REPORT CRPL-9-1

NOVEMBER 8,1946

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CENTRAL RADIO PROPAGATION LABORATORY
WASHINGTON, D. C.

TERMINAL REPORT OF MICROWAVE MEASUREMENT STANDARDS SECTION ON VERY HIGH FREQUENCY FIELD INTENSITY STANDARDS

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By H. E. SORROWS, R. C. ELLENWOOD
and
W. E. RYAN

I. Introduction

This report includes the planning and preliminary investigation of problems relating to field intensity standards in the VHF band from 40 to 160 megacycles per second, specifically covering the standards necessary for frequency modulation, television, and navigational aid equipment for C.A.A. It was the plan to set up standards for comparison purposes in as short a time as possible to take care of expected post-war needs. The work of the Microwave Measurement Standards Section on field intensity standards for the VHF band is terminated by this report. Equipment developed will be turned over to the Ionospheric Measurement Standards Section pr eparatory to their assumption of responsibility for the program in this band, since the Ionospheric Measurement Section is responsible for standards in this frequency range. This report was prepared as an instruction book to aid in the transition of the work.

Calibration of field intensity measuring equipment in any range consists of two types of problems. These are (1) the calibration and checking of internal circuits, and (2) the calibration of the antenna system. The calibrations must be made over the frequency bands for which the instrument will be used.

II. Calibration of the Internal Circuits

The calibration of the internal circuits of a field intensity meter can be best discussed by referring to a block diagram (Fig. 1) of the commonly used type of meter.

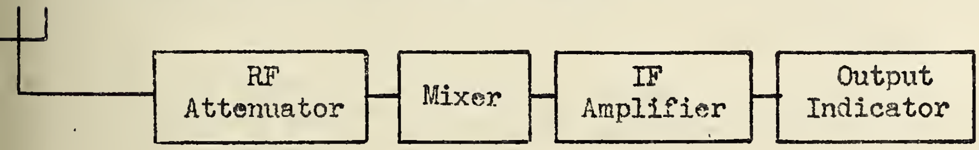

Fig. 1
Block Diagram of Typical
V.H.F. Field Intensity Meter

The linearity and stability of the output indicator must be checked and this may be done, in most cases, with DC equipment. The linearity and stability of the IF amplifier must be checked at the intermediate frequency and the mixer must be checked over the entire frequency reception band. This requires a method of supplying known values of VHF and IF voltages. This can be a standard RF voltage generator with an associated calibrated attenuator. A waveguide below cut-off or mutual inductance type attenuator is preferable because small increments of attenuation can be read with precision. Since equipment necessary to perform the above functions is in the Central Radio Propagation Laboratory at the present time, or available commercially, the major part of our effort was spent on the problem of the overall calibration of field intensity meters. This includes the calibration of the effective length of the antenna as well as the gain of the associated circuits of the meter.

III. Overall Calibration of VHF Field Intensity Meters

There have been two rather obvious techniques used in the past for the overall calibration of field intensity meters. The simpler and more commonly used procedure can be referred to as the substitution method. The received field intensity may be calculated by the ratio of the voltage at the feed-point of the antenna to the effective length of the antenna. The effective length is calculated from the dimensions and structure of the antenna. A given VHF voltage value at the feed-point may be obtained by removing the antenna and substituting a VHF voltage from a standard voltage generator. Since the effective length of the antenna and the VHF voltage at the base of the antenna are assumed to be known, the field intensity may be calculated. A weakness of this method is that the standard voltage generator is usually so designed that the indicated voltage is within the generator. The voltage at the output terminals is assumed to be the same value. When used with a field intensity meter, it is assumed that a perfect match exists between the receiving terminals of the meter and the signal generator, which is seldom true. The magnitude of the error depends upon the amount of mismatch. The mismatch is difficult to measure accurately since the transmission line to the field intensity meter is usually of the balanced parallel conductor type.

A more fundamental method of overall calibration of field intensity meters is to place the receiving antenna in a known VHF field and correlate this known field with the meter output indication. It is necessary that the circuits of the meter be operated with normal gain during calibration and care must be taken to set the circuits for the same gain when measurements are made with the field intensity meter. This known VHF field intensity may be referred to as the standard field and must be evaluated by measuring the power into a transmitter antenna and calculating the field intensity at a desired position in space. There have been a large number of papers written on the theory of wave propagation, of which only a few, References 1, 2, 3, 4, 10, 11, 14, 15, 16, and 17, are listed in the bibliography. It was the plan to accept the existing formulas for calculation of field intensity and then develop and improve the measurement technique. It is hoped that it will be possible to check and calibrate field intensity meters in a standard field to an accuracy of better than 10%. This accuracy would be quite sufficient at present.

IV. Equipment

The following section of the report will be a discussion of the equipment designed for the purpose of making an overall calibration of field intensity meters and of making any tests considered necessary for substantiating the results.

A. Equipment Designed to Calibrate VHF Field Intensity Meters by the Substitution Method:

Two devices were designed to eliminate the error in calibration caused by mismatch between the output terminals of the VHF standard voltage generator and the antenna input terminals of the field intensity meter. Although these devices use different voltage indicators, they perform identical functions. They were built to give cross-checks with each other and to determine which was the more practical to use. They measure the VHF voltage across the input to the field intensity meter at the exact electrical position where the antenna is connected when used. One device uses a thermistor and the other a diode to measure the VHF voltage.

1. Thermistor Bridge Voltmeter

The first device, Fig. 2, utilizes a thermistor as a resistance arm of a wheatstone bridge to measure the VHF voltage across its terminals. The bridge is used in an unbalanced condition to give the sensitivity needed since the VHF input power to the thermistor must be limited to 50 microwatts or less. (Input voltage to the field intensity meter must be limited to 0.1 volt and is measured across a thermistor of 200 ohms impedance). The thermistor, wheatstone bridge resistance arms and the tuned VHF chokes were enclosed in a brass box to insure maximum ambient temperature stability and convenience of operation.

2. Diode Voltmeter

The second device, a VHF voltmeter incorporating a diode, is shown in Fig. 3. It was designed as a convenient method of determining the VHF voltage at the same electrical position as that of the feed-point of the antenna. The advantage of the device over the thermistor bridge is that the indication of voltage is independent of ambient temperature for all practical temperatures. Voltages less than 0.1 volt cannot be measured satisfactorily with diode voltmeters. To overcome this difficulty, the voltage generator can be operated at a level which gives 1 volt across the diode voltmeter; then, the voltage generator output is decreased by a desired ratio leaving a known voltage of 0.1 volt or less across the diode voltmeter. The resistance attenuator pad between the diode voltmeter and the voltage generator makes possible the operation of the VHF voltage generator at a high enough output so that the ratio by which the generator output is decreased can be measured accurately. The exact attenuation and frequency dependence of the attenuation pad is unimportant and was not measured.

To calibrate the diode voltmeter,readings of an AF input voltage (2000 c/s) versus output indication of the diode voltmeter were taken and are shown in Graph No. 1. This may be used at VHF by using a correction factor which is dependent on frequency.

B. Equipment Designed to Generate the Standard Field

In order to obtain a satisfactory overall calibration of a field intensity meter, a standard VHF field is generated in which the receiver antenna is placed. The operation of the meter during calibration is similar to the operation when in use. Such a calibration is acceptable if it can be demonstrated that the standard field has the same value as calculated. One method of checking the standard field is to compare it with the field strength determined by a standard receiving antenna. This standard receiving antenna consists of a half wave dipole of known effective length and equipment for measuring the voltage produced at its output terminals. The standard antenna system constructed was quite insensitive compared to the super-heterodyne receiver type of field intensity meters; therefore, the standard field generated must be of rather large magnitude. This requires VHF voltage sources of sufficient power and stability to permit precision measurements.

1. VHF Voltage Generators

The following voltage generators were used to drive the transmitting antennas, to set up the standard field, and to make impedance measurements. Since the commercially available VHF voltage generators do not have sufficient power output or adequate shielding, it was necessary to design and construct two generators to cover the desired frequency band. Tracked "inline" variable condensers are used in the oscillator and buffer amplifier stages. These condensers are driven with a National Company NPW-0 dial and gear drive unit to give accurate, reproducible tuning with vernier control. A buffer stage was used to make the operating frequency independent of the output load and to give a convenient method of controlling the VHF voltage output. The output is adjusted by varying the screen voltage of the buffer stage. This output is measured with a diode voltmeter. It was found that the push-pull balanced voltage generator as constructed failed to give a balanced output voltage over the entire frequency band. Therefore, it is considered necessary to couple the output loop of the voltage generator into a single conductor coaxial line which consequently requires some type of a conversion unit to transform from the unbalanced voltage output to the balanced transmitting antenna system.

(a) 40 to 90 Mc/s voltage generator (Fig. 4A).

This VHF voltage generator was designed to have continuous tuning to cover the frequency band from 40 to 90 Mc/s with a maximum power output of approximately 5 watts. It requires a 400 volt DC supply at 80 milliamperes. The filament requirement is 6.3 volts at 7 amperes. DC should not be applied to the filaments since the blower is attached to the filaments and is AC operated. The operating frequency versus dial reading is read from Graph 2.

(b) 90 to 160 Mc/s voltage generator (Fig. 4B).

This generator was designed to have continuous tuning and adjustable output voltage with a maximum power output of approximately 10 watts. The power output was not checked. The generator requires a 750 volt DC power supply at 150 milliamperes. The filament requirement is 6.3 volts at 9 amperes. DC should not be applied to the filament since the blower is attached to the filament circuit and is AC operated. The measured values offrequency versus dial readings are shown by Graph 3.

2. DC Voltage Regulated Power Supplies

The commercially available regulated power supplies which could be used for driving the VHF voltage generators were found inadequate because of instability and excessive weight. The DC output voltage of the commercial supplies was found to vary as much as 1% due to usual line voltage changes and from drift attributed to changing characteristics of some of the components. Two power supplies were designed and constructed to obtain the high stability required. Specifications and results of the tests performed are as follows:

(a) The first regulated power supply (Fig. 5A) delivers 400 volts DC with a maximum current of 80 milliamperes. It also supplies 6.3 volts AC at 7 amperes. The physical dimensions are 10.5" x 21" x 14.75". It weighs approximately 50 pounds. The output connections are on a terminal strip located at the rear of the cabinet. The power supply is not grounded to the chassis. The ripple is less than 60 millivolts peak to peak. All resistors that may affect the stability of the output voltage are wire wound. The results of tests to determine percentage change of DC output voltage with change of output load and with change of line voltage are given by Graph 4. It will be noted that the maximum change of output voltage was 0.006% for a change of AC input voltage from 100 to 130 volts and was 0.06% for a change of output current from 0 to 80 milliamperes. Drift of output voltage was less than .01% during a one hour observation period.

Caution: Do not turn on plate voltage switch until the filaments have been on for 30 seconds to avoid damaging the mercury vapor rectifiers.

b. The DC voltage regulated power supply (Fig. 5B) which was designed to supply 750 volts at 150 milliamperes DC output has AC filament supply of 6.3 volts at 10 amperes. The power supply is not grounded to the chassis. The physical dimensions are 10.25" x 21" x 14.75" and the weight is approximately 60 pounds. The output connections are located at the rear of the cabinet on a terminal strip. The ripple is less than 60 millivolts peak to peak. Resistors that affect the stability of the output voltage are wire wound. Results of the tests to determine the percentage change of DC output voltage with change of output load and also with change of line input voltage are shown by Graph 5. Drift of output voltage was found to be less than .01% during a one hour observation period.

3. Wide-band Transformers (Bazookas)

To transmit VHF power from the unbalanced output of the voltage generator to the balanced antenna system, it is convenient to use an unbalanced to balanced, wide-band, transmission line type transformer (Fig. 6). This transformer is commonly called a bazooka or balun. It has a theoretical band width from 1/2 to 3/2 of center frequency with approximately constant phase and impedance ratios. Two units were constructed. One has a center frequency of 75 Mc/s and the other has a center frequency of 150 Mc/s. They were designed to have an input and output resistance of 75 ohms.

4. VHF Power Meter

A preliminary model of a hot wire power measuring device (Fig. 7) was built to measure the VHF power supplied to the transmitting antenna. The hot wire elements are used to measure current and voltage at the base of the transmitting antenna. It is desirable to measure current and voltage at the driving point of the antenna when transmitting the standard field to determine the magnitude of the antenna impedance. The hot wire elements were chosen in preference to thermoelements because of their relative freedom from the effect of ambient temperature change. A photocell is used to determine the power dissipated by the hot wire element. The current and voltage may be read from the calibration curves shown in Graphs 6 and 7. The number of the element as given in the Graph corresponds to the number found on the housing of the hot wire elements. It will be necessary to improve the design of the present model to eliminate radiation from the connecting terminals and to eliminate the reactive impedance as seen at the input terminals.

C. Miscellaneous Equipment Designed to be Used in the Standardization Program

1. Standard Receiving Antenna.

The standard receiving antenna (Fig. 8) is used to check the value of field intensity, at a given position in space, as calculated from the measured value of power into the transmitting antenna. It consists of an adjustable half-wave dipole which feeds a thermoelement with a heater of approximately 75 ohms resistance. This element is used to determine the power received by the antenna. A precautionary note should be added regarding the use of thermoelements. Since these devices are sensitive to ambient temperatures, care should be taken that they are operated at the ambient temperature at which they are calibrated. A calibration of the thermoelement is shown in Graph 8.

2. Antenna Impedance Measuring Device.

In the measurement of field intensity, there arises the problem of determining the impedance of an antenna system as a function of the height above the earth's surface. It was considered possible to determine the effective reflection coefficient and the earth constants by measuring an antenna impedance as a function of the antenna height above the earth's surface. To perform this experimental work, a single-frequency bazooka attached to a one-half wave length antenna (Fig. 9) was built to be used with an impedance measuring device such as a standing wave machine.

V. Setting up and Calculating the Standard Field

A site for setting up the standard field was selected on the grounds of the Sterling Radio Propagation Laboratory. The site is a moderately level tract of land without obstructions, such as trees or buildings, with dimensions of approximately 800 meters square. Plans have been made to level an area 200 by 600 meters in the center of the tract. A portable gasoline engine driven, 60 cycle, 110 volt generator is used to provide power until an underground hut with buried power lines is constructed in the center of the leveled area. This site will make it possible to calibrate and check field intensity meters mounted in station wagons or cars. It will be possible to simulate conditions under which meters are used. Calibration includes the effect of the car body and orientation of the car with respect to the direction of travel of the received VHF wave on the field intensity measured. At a later date, a wire mesh may be laid over the leveled areato approximate a perfectly conducting plane surface. The calculations of the standard field intensity would then be independent of the ground constants.

During the calibration of a field intensity meter the transmitting antenna used to establish the standard field is placed at a measured distance from the receiving antenna of the field intensity meter at a given height above the ground. The standard field at the receiving antenna is calculated from the power into the transmitting antenna and the boundary conditions. This RF field may be considered as the vector sum of three component waves. One of the waves travels directly from the transmitter to receiver through the air and is termed the direct wave. Another of the waves may be considered to be reflected from the ground before reaching the receiving antenna and is termed the ground-reflected wave. The third wave is termed the surface wave. This wave is thought of as traveling along the surface of the bounding medium which is a plane surface in this problem. When the transmitting and receiving antennas are located near or on the surface of the earth, power is furnished by this wave to the imperfectly conducting boundary surface of the earth. The direct and ground-reflected waves combine into what is called the space wave. This terminology seems to be accepted by most writers and is obtained from the reports and articles by K. A. Norton. These papers should be referred to for the derivation of the general equations for propagation of RF waves over the surface of the earth. The formula used to calculate the vector sum of the surface and space waves is found in Norton's report on The Calculation of Ground Wave Field Intensity over a Finitely Conducting Spherical Earth.

The ground wave field intensity at short distances over a plane earth is given by the following formula:

$$\xi = \frac{\xi_0}{d}\left[\overbrace{\overbrace{\cos^3\psi_1\, e^{\frac{j2\pi R_1}{\lambda}}}^{\text{Direct Wave}} + \overbrace{\underline{R}\,\cos^3\psi_2\, e^{\frac{j2\pi R_2}{\lambda}}}^{\text{Ground-reflected Wave}}}^{\text{SPACE WAVE}} + \overbrace{(1-\underline{R})\; f(P,B)\cos^2\psi_2\, e^{j\left(\frac{2\pi R_2}{\lambda}+\phi\right)}}^{\text{Surface Wave}}\right]$$

where:

ξ = Field intensity at position in question, the receiving antenna.

ξ_0 = Field intensity at a unit distance from the transmitter, considered in free space.

d = Horizontal distance between transmitter and receiving antenna

R_1 = length of direct path between transmitter and receiver antenna.

R_2 = length of path of indirect wave from transmitter to receiver antenna.

ψ_1 = angle between direct wave path from the transmitter to receiver and the earth's surface

ψ_2 = angle between indirect wave path from the transmitter to receiver and the earth's surface.

$\underline{R}$ = reflection coefficient

$f(P,B)e^{j\phi}$ = surface wave attenuation function which is found as follows:

$$f(P,B) = 1 + j\sqrt{\pi P_1}\, e^{-P_1} \operatorname{erfc}(-j\sqrt{P_1})$$

where

$$P_1 = Pe^{jB}$$

and

$$\operatorname{erfc}(-j\sqrt{P_1}) \equiv j\frac{2}{\pi}\int_{i\infty}^{\sqrt{P_1}} e^{y^2}\,dy$$

and

$$Pe^{jB} = \frac{\pi R_2 X}{\lambda \cos b'}\left[1 + \frac{(h_1+h_2)}{R_2}\left(\frac{X}{\cos b'}\right)^{-\frac{1}{2}} e^{j\left(b' - \frac{3\pi}{4}\right)}\right]^2 e^{j(\pi - b')}$$

$$b' = \mathrm{TAN}^{-1}\left(\frac{\epsilon - \cos^2\psi_2}{X}\right)$$

$$X = \frac{1.79731 \cdot 10^{15}}{f_{Mc/s}}\,\sigma \text{ emu}$$

where

ϵ = dielectric constant of the earth

σ = conductivity of the earth

f = frequency

h_1 = height of transmitting antenna above the earth's surface (meters).

h_2 = height of receiving antenna above the earth's surface (meters).

λ = wavelength in free space.

Since the value of P was very large, the following series was used for calculations:

$$f(P,B)e^{j\phi} = -\frac{1}{2P_1} - \frac{1\cdot 3}{(2P_1)^2} - \frac{1\cdot 3\cdot 5}{(2P_1)^3} - \ldots .$$

Figure 10 gives a picture of the wave paths and location of receiving and transmitting antennas. The values for (d, R_1, R_2, λ) may be obtained by measurement and they should be evaluated in the same units. The values for $\underline{R}$ and f (P,B) must be calculated from the ground constants, height of antennas above the ground and spacing between them.

Choice of antenna heights above the earth's surface, spacing between antennas, and the polarization must be made to establish the standard field. Consideration must be given to convenience of operation of equipment, the magnitude of possible error caused by erroneous values of ground constants, and the possibility of field components which could be considered negligible. Horizontal polarization of the electric vector, antenna heights of the order of one-half wave length or more, and spacing of from 20 to 300 meters were chosen as the most practical conditions to use in the beginning of the experimental work. Low antenna heights approximately one-half wave length or so enable the operator to set up and adjust the antennas and associated equipment with a minimum effort. The major reason for the low heights is apparent from a study of the reflection coefficient formula which can be shown to be as follows:

$$\underline{R}_H = \frac{\sin\psi_2 - \sqrt{\left(\frac{N_2}{N_1}\right)^2 - \cos^2\psi_2}}{\sin\psi_2 + \sqrt{\left(\frac{N_2}{N_1}\right)^2 - \cos^2\psi_2}}$$

$\underline{R}_H$ = reflection coefficient for an electromagnetic wave with the electric vector perpendicular to the plane of incidence.

$N_1 = 1$ = index of refraction of air.

$N_2 = \sqrt{\epsilon + j\chi}$ = index of refraction of the soil.

Since the earth's surface is not a perfect conductor, $\underline{R}_H$ will consist of a real and imaginary term which will be represented by R_H' and R_H'', respectively.

$$\underline{R}_H = R_H' + j\, R_H''$$

where

$$R_H' = \frac{\sin^2\psi_2 \quad \cos b' - x}{\sin^2\psi_2 \quad \cos b' + x + 2\sin\psi_2 \cos\left(\frac{b'}{2} - 45°\right)\sqrt{x \cos b'}}$$

$$R_H'' = \frac{2\sin\psi_2 \quad \sin\left(\frac{b'}{2} - 45°\right)\sqrt{x \cos b'}}{\sin^2\psi_2 \quad \cos b' + x + 2\sin\psi_2 \quad \cos\left(\frac{b'}{2} - 45°\right)\sqrt{x \cos b'}}$$

(ψ_2 , b' , x) have been defined previously.

It is apparent from the above equations that as ψ_2 approaches 0°, $\underline{R}_H$ approaches -1 and is less dependent on the ground constants. Since the surface wave attenuation factor is large for horizontal polarization, it is possible for the surface wave component of the standard field intensity to become negligible, even for close spacing of the transmitting and receiving antennas.

A set of rigorous calculations were made to determine the value of the components of the standard field as a function of distance from the transmitting antenna. The transmitting and the receiving antenna heights above the earth's surface were chosen as 1-1/2 meters each and their spacing was from 20 to 350 meters. The earth's surface was considered to be a plane surface. The earth was considered to be of a homogeneous material with average soil constants of 15 for the dielectric constant and 5×10^{-14} emu for the conductivity. The transmitting and receiving antennas were taken as 1/2 wavelength electric dipoles. The frequencies used were 50, 100, and 150 Mc/s. During experimental work, the antennas would be spaced so that only the radiation field need be considered. While making these rigorous calculations, several parameters were tabulated and graphs drawn so that future calculations could be made easily.

The reflection coefficient was divided into the real and imaginary parts, R_H' and R_H'', respectively and plotted (Graph No. 9) against the angle ψ_2 . This enables the reflection coefficient to be read directly from the graphs. The ratio of the surface wave to the space wave was calculated as a function of distance from the transmitting antenna

(Graph No. 10) to determine whether the surface wave could be neglected in future calculations. In Graph No. 11, the ratio of $\mathcal{E}$ (the standard field intensity) to $\mathcal{E}_0$ (the free space field intensity at a unit distance from the transmitter) was plotted against the distance from the transmitter to facilitate making calculations in the field. The field intensity at a given distance from the transmitter may be readily obtained by selecting the ratio from the above graph, by which $\mathcal{E}_0$ must be multiplied. The antenna heights must be 1-1/2 meters and the ground constants the same as those used in the calculations for this graph to be applicable. The value of $\mathcal{E}_0$ may be calculated from the following formula in which the unit distance is one meter:

$$\mathcal{E}_0 = \frac{60\pi \ell I}{\lambda}$$

where

$\mathcal{E}_0$ = field intensity in volts/meter

ℓ = effective length of transmitting antenna in meters

I = VHF current measured at the terminals of the antenna (amperes).

The value of $\mathcal{E}_0$ obtained at a unit distance is used only for calculation and does not represent the total field intensity at 1 meter from the transmitter antenna since field components other than the radiation fields have been neglected.

In the calculation of ground wave propagation over a plane earth, the effect of subterranean discontinuities must be considered. Fig. 11 shows an idealized example of the travel of the ground-reflected wave when discontinuities are below the earth's surface. Given the conductivity and dielectric constants of the earth and the subterranean rock layer, the error introduced by the rock layer may be calculated if the depth (d) beneath the surface, angle ψ_2, and the fre quency are known. To determine the magnitude of the largest possible error in calculation of field intensity caused by these discontinuities, the rock base was considered to be a perfect reflector and the value of $E_{TR\,T'}$ was compared with the value of the ground-reflected wave (E_R). The effect of the attenuation of the earth was included in the calculations. E_R is the value of the ground-reflected wave when the earth was considered homogeneous. Preliminary calculations indicated that the presence of a perfect conductor closer than several meters below the reflecting surface of the earth could seriously alter the standard field. This problem should be carefully examined. It may be found necessary to cover the surface with a wire mat to eliminate the effect of subterranean discontinuities, heterogeneities, and ground constants changing with the weather.

Conclusion

The experimental field work planned has not been carried out since the work was terminated at the stage given in this report preparatory to turning the project over to the Ionospheric Measurement Standards Section, as standards in the frequency range for which this section is responsible. Preliminary models of the equipment have been designed and constructed as shown in the photographs but they have not been set up to determine the overall operating characteristics of the system. Preliminary calculations and the correlated graphs should be useful in making future calculations. Numerical data on which the graphs are based will be on file in the Microwave Measurement Standards Section. They were considered too bulky to be incorporated in this report. Such numerical data had to be calculated in full since published graphical material suitable for computation of wave propagation does not cover the transmitter-receiver distances used for field intensity standards work. There were no calculations made on the problem of determining the ground constants by measuring the antenna impedance as a function of height above ground.

Acknowledgments

The authors wish to acknowledge the useful advice obtained from Dr. Harold Lyons and Messrs. W. F. Snyder and J. J. Freeman. Thanks are due Messrs. F. Reggia and S. Miller for their cooperation and for their skillful construction of equipment.

A List of the Equipment Constructed is as Follows:

Thermistor Bridge		Photo No. 1(a)
Attenuator Pad - Diode Voltmeter		Photo No. 1(b)
Standard Voltage Generator	(40 - 90 Mc/s)	Photo No. 2(a)
Standard Voltage Generator	(90 - 160 Mc/s)	Photo No. 2(b)
Regulated Power Supply	(400 Volts - 80 Ma DC output)	Photo No. 2(c)
Regulated Power Supply	(750 Volts - 150 Ma DC output)	Photo No. 2(d)
Wide Band Transmission Line Transformer	(center frequency - 75 Mc/s)	Photo No. 1(c)
Wide Band Transmission Line Transformer	(center frequency - 150 Mc/s)	Photo No. 1(d)
Power Meter		Photo No. 3(c)
Standard Receiving Antenna	(adjustable)	Photo No. 3(b)
Antenna Impedance Measuring Device		Photo No. 3(a)

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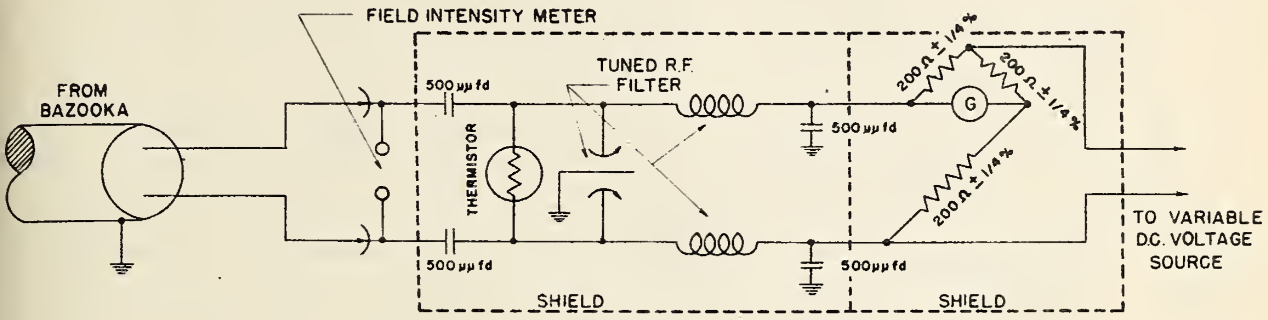
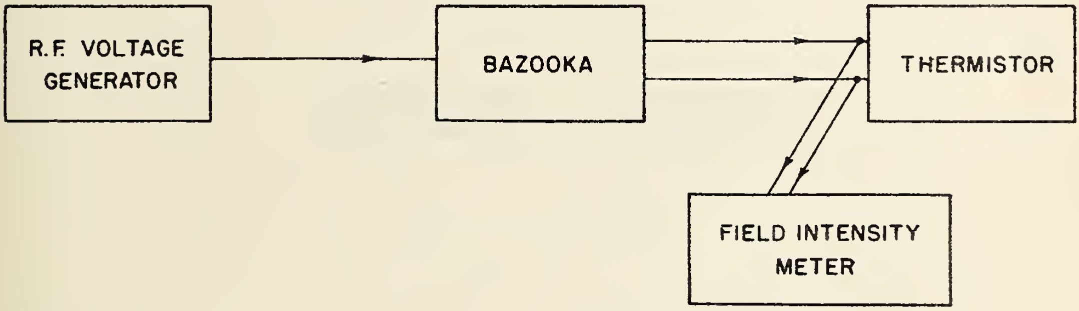

FIELD INTENSITY METER
FROM BAZOOKA
500 μμfd
TUNED R.F. FILTER
THERMISTOR
500 μμfd
500 μμfd
500 μμfd
200 Ω ± 1/4%
200 Ω ± 1/4%
200 Ω ± 1/4%
G
SHIELD
SHIELD
TO VARIABLE D.C. VOLTAGE SOURCE

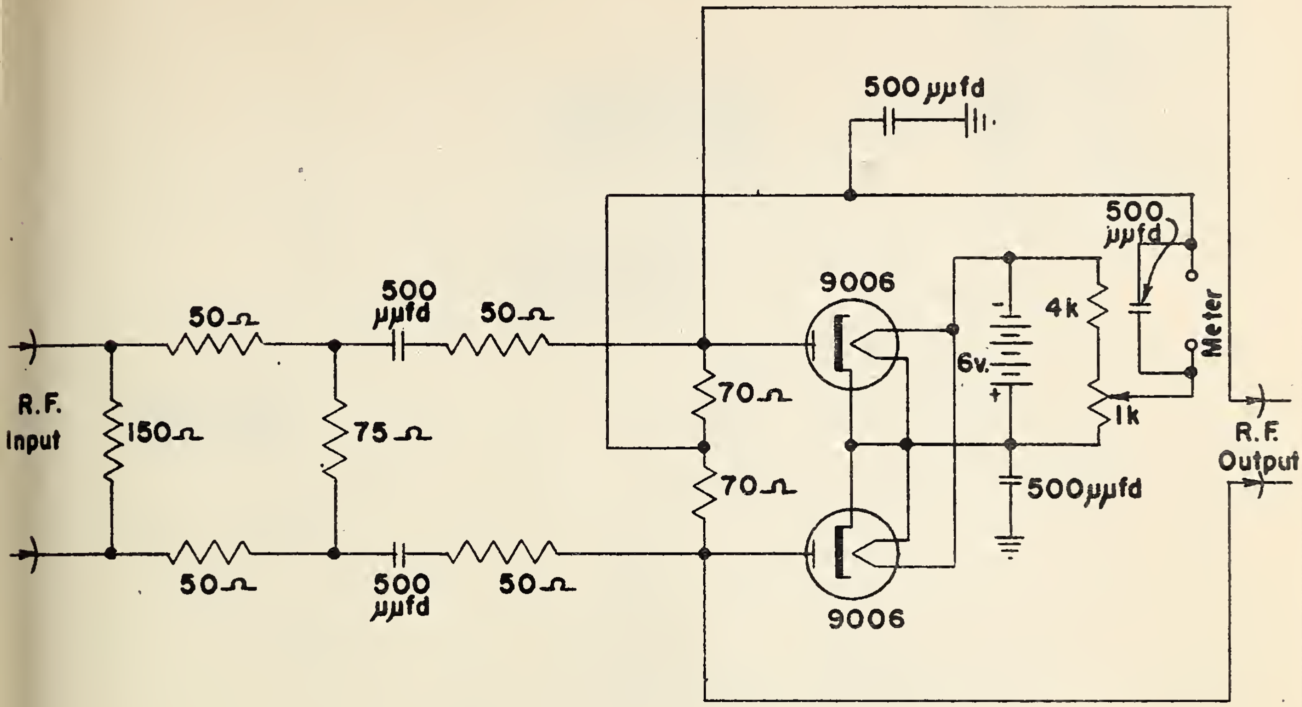
SCHEMATIC DIAGRAM


R.F. VOLTAGE GENERATOR
BAZOOKA
THERMISTOR
FIELD INTENSITY METER

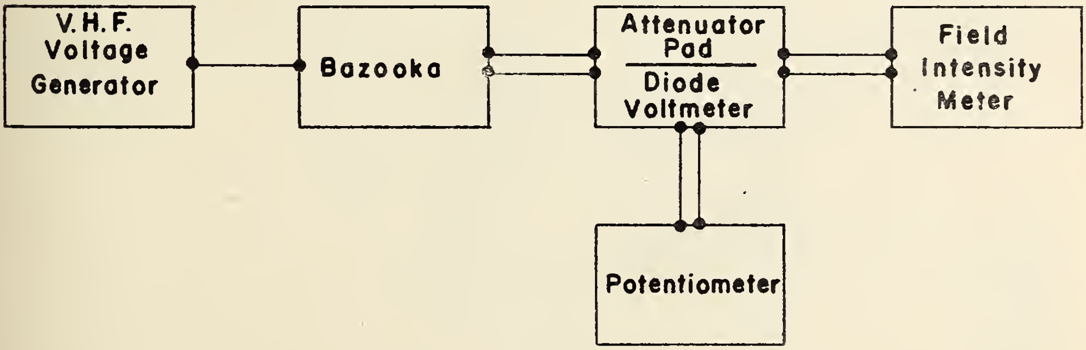
BLOCK DIAGRAM OF BRIDGE IN OPERATION

THERMISTOR BRIDGE

FIG. 2


500 μμfd
500
μμfd
9006
500
μμfd
50Ω
50Ω
4k
Meter
6v.
R.F.
Input
150Ω
75Ω
70Ω
1k
R.F.
Output
70Ω
500μμfd
50Ω
500
μμfd
50Ω
9006

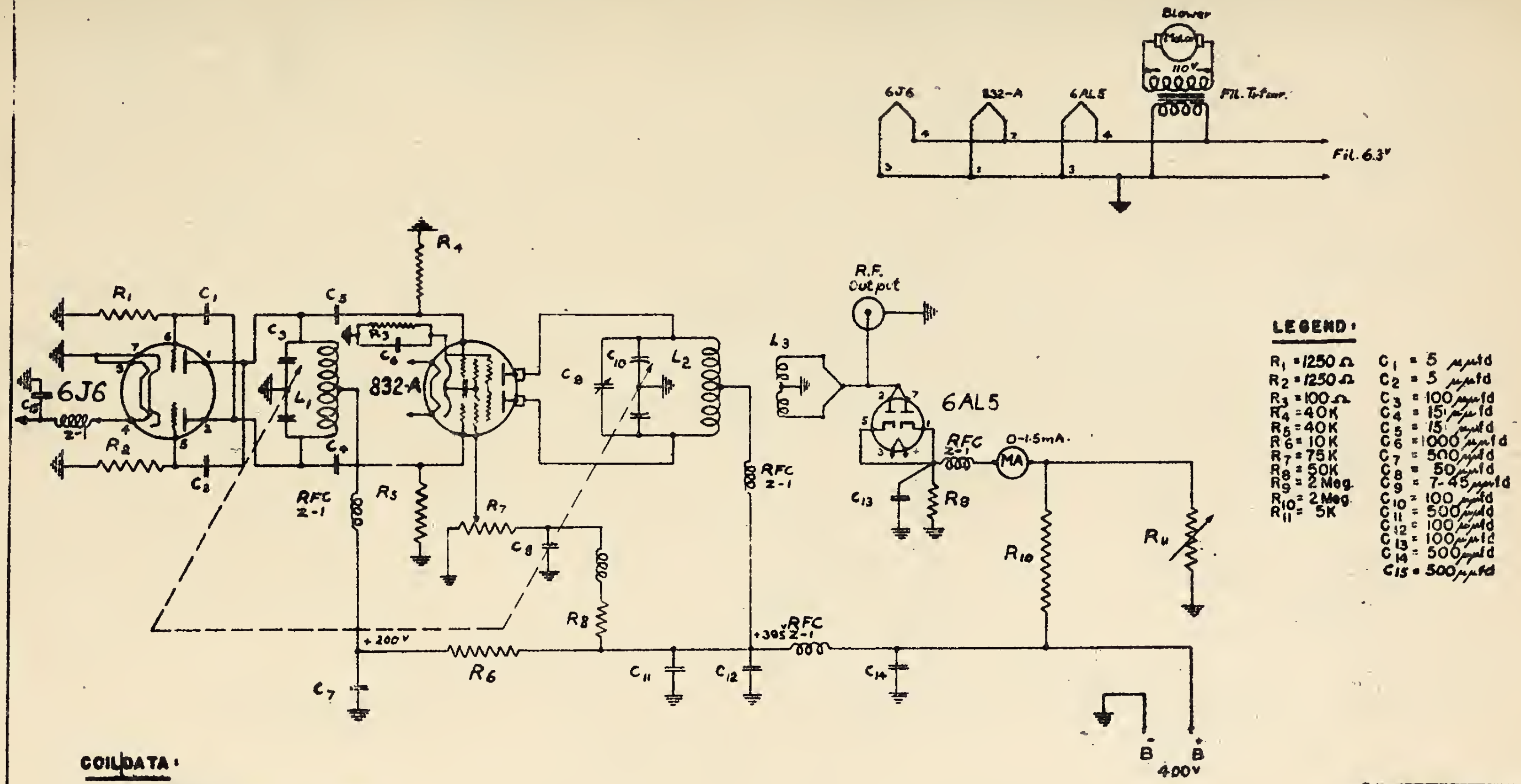
Schematic Diagram


V.H.F.
Voltage
Generator
Bazooka
Attenuator
Pad
Diode
Voltmeter
Field
Intensity
Meter
Potentiometer

Block Diagram of Device in Operation

Fig. 3

ATTENUATOR PAD—DIODE VOLTMETER


Blower
Motor
110V
Fil. Tsfmr.
6J6
832-A
6AL5
Fil. 6.3V
R1
C1
C5
R4
C3
R3
C6
L1
832-A
6J6
C15
Z-1
R2
C2
C4
RFC Z-1
R5
R7
C8
R8
C9
C10
L2
RFC Z-1
L3
R.F. Output
6AL5
RFC Z-1
0-1.5mA.
MA
C13
R9
R10
R11
+200V
R6
C7
C11
C12
+305V
RFC Z-1
C14
B-
B+
400V

LEGEND:

R1 = 1250 Ω
R2 = 1250 Ω
R3 = 100 Ω
R4 = 40K
R5 = 40K
R6 = 10K
R7 = 75K
R8 = 50K
R9 = 2 Meg.
R10 = 2 Meg.
R11 = 5K

C1 = 5 μμfd
C2 = 5 μμfd
C3 = 100 μμfd
C4 = 15 μμfd
C5 = 15 μμfd
C6 = 1000 μμfd
C7 = 500 μμfd
C8 = 50 μμfd
C9 = 7-45 μμfd
C10 = 100 μμfd
C11 = 500 μμfd
C12 = 100 μμfd
C13 = 100 μμfd
C14 = 500 μμfd
C15 = 500 μμfd

COIL DATA:

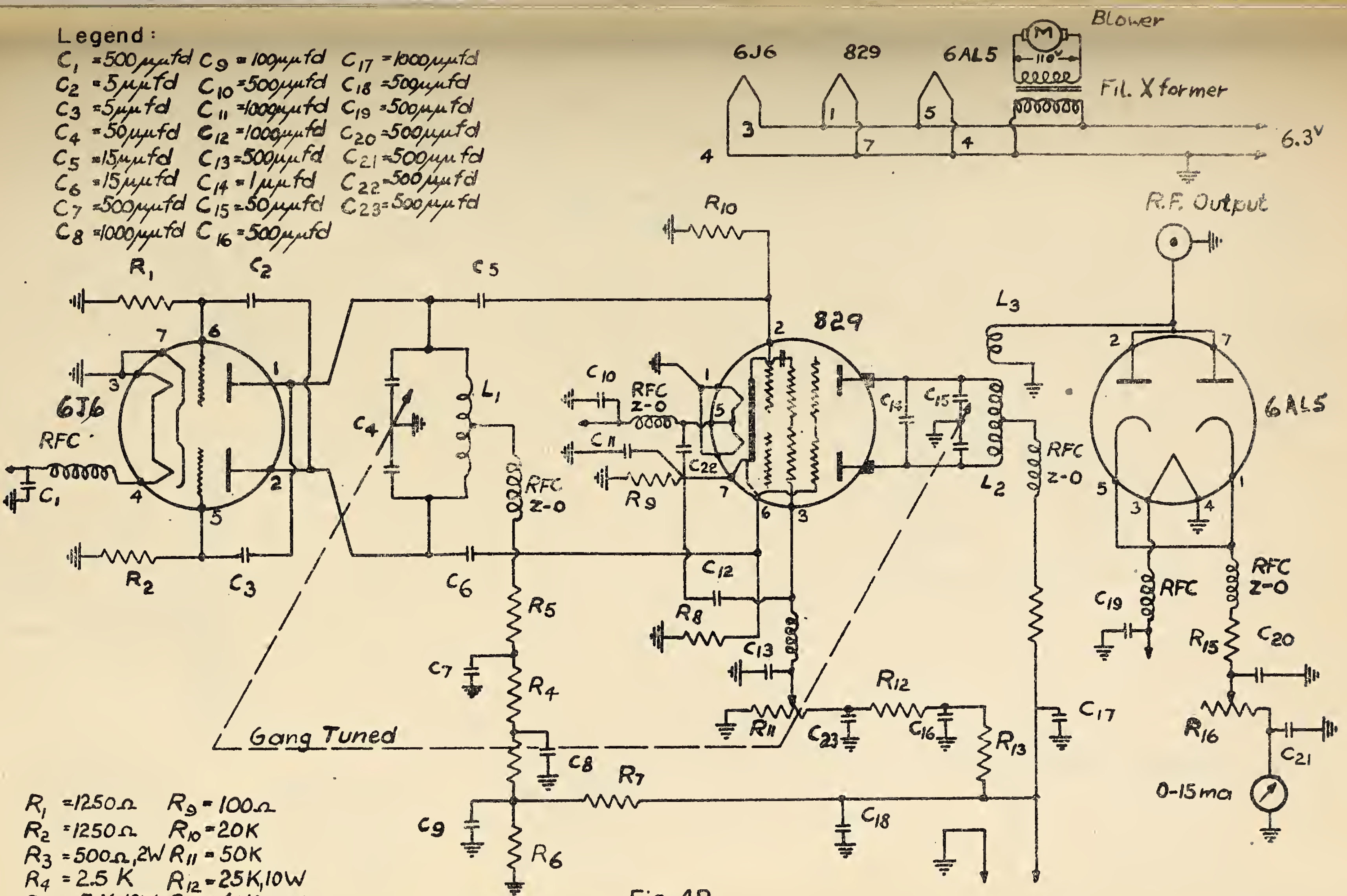
L1, L2 : 4 turns of #12 wire per inch
I.D.: 3/8".
L3 : #12 wire, 5/8" Diameter
2 turns wound clockwise
2 turns wound counterclockwise
with 1 inch opening between them.

Fig. 4A

Schematic
NATIONAL BUREAU OF STANDARDS
WASHINGTON D.C.
RADIO SECTION
STANDARD VOLTAGE GENERATOR (40-90 Mc/s)
DESIGNER F.R. DATE 1-46 SCALE
DELINEATOR AAF 10/2/46 SHEET NO 1 of 1
CHECKER
APPROVAL H. DRAWING

Legend:

C_1 = 500 μμfd
C_2 = 5 μμfd
C_3 = 5 μμfd
C_4 = 50 μμfd
C_5 = 15 μμfd
C_6 = 15 μμfd
C_7 = 500 μμfd
C_8 = 1000 μμfd
C_9 = 100 μμfd
C_{10} = 500 μμfd
C_{11} = 1000 μμfd
C_{12} = 1000 μμfd
C_{13} = 500 μμfd
C_{14} = 1 μμfd
C_{15} = 50 μμfd
C_{16} = 500 μμfd
C_{17} = 1000 μμfd
C_{18} = 500 μμfd
C_{19} = 500 μμfd
C_{20} = 500 μμfd
C_{21} = 500 μμfd
C_{22} = 500 μμfd
C_{23} = 500 μμfd

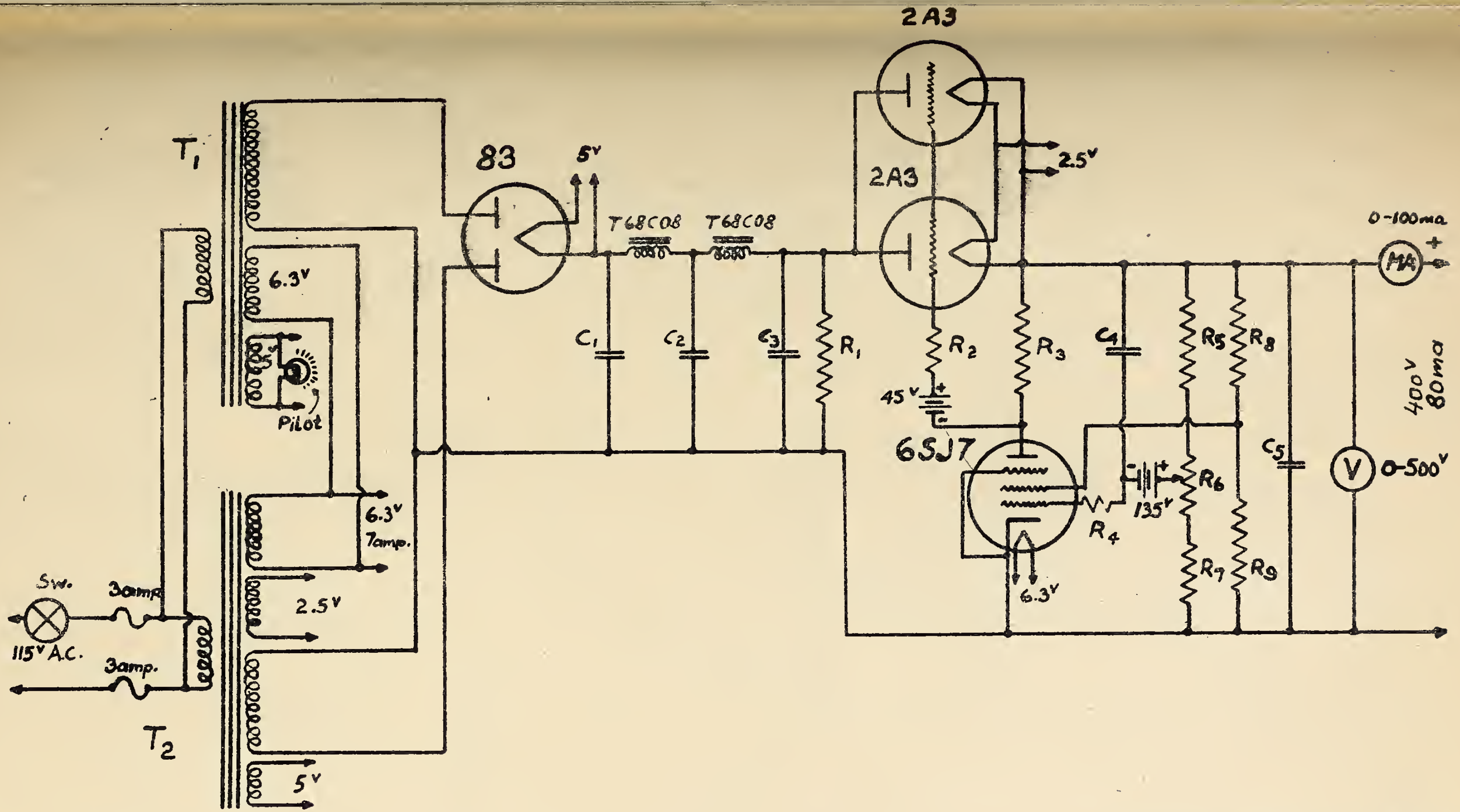

6J6
829
6AL5
Blower
M
110V
Fil. X former
3
1
5
7
4
4
6.3V
R.F. Output
R_{10}
R_1
C_2
C_5
L_3
2
829
7
6
1
2
6AL5
3
6J6
RFC
C_1
4
5
2
C_4
L_1
C_{10}
RFC
Z-0
C_{11}
R_9
C_{22}
1
5
7
6
3
C_{14}
C_{15}
L_2
RFC
Z-0
5
3
4
1
RFC
Z-0
RFC
C_{19}
R_2
C_3
C_6
C_{12}
R_5
R_8
C_{13}
R_{15}
C_{20}
C_7
R_4
R_{12}
R_{11}
C_{23}
C_{16}
R_{13}
C_{17}
R_{16}
C_{21}
Gang Tuned
C_8
R_7
0-15ma
C_9
C_{18}
R_6

R_1 = 1250 Ω
R_2 = 1250 Ω
R_3 = 500 Ω, 2W
R_4 = 2.5 K
R_5 = 5 K, 10W
R_6 = 50K, 10W
R_7 = 4K, 10W
R_8 = 20K
R_9 = 100 Ω
R_{10} = 20K
R_{11} = 50K
R_{12} = 25K, 10W
R_{13} = 40K, 10W
R_{14} = 50 Ω, 2W
R_{15} = 5K, 2W
R_{16} = 5K.

Fig. 4B.

Coil Data:
L1, L2, → 2 turns # 12 wire/¾ inch
Inside Diameter → ⅝ inch
L3; → 2 turns # 12 wire / ¾ inch
Inside Diameter — ½ inch

5W-VOLTAGE GENERATOR
90-160 Mc/sec.
N.B.S. MAY 1946


2A3
2A3
T₁
83
5ᵛ
T68C08
T68C08
2.5ᵛ
0-100ma
+
MA
6.3ᵛ
C₁
C₂
C₃
R₁
R₂
R₃
C₄
R₅
R₈
400ᵛ
80ma
45ᵛ
Pilot
6SJ7
C₅
R₆
V
0-500ᵛ
6.3ᵛ
7amp.
135ᵛ
R₄
Sw.
3amp.
2.5ᵛ
R₇
R₉
6.3ᵛ
115ᵛ A.C.
3amp.
T₂
5ᵛ

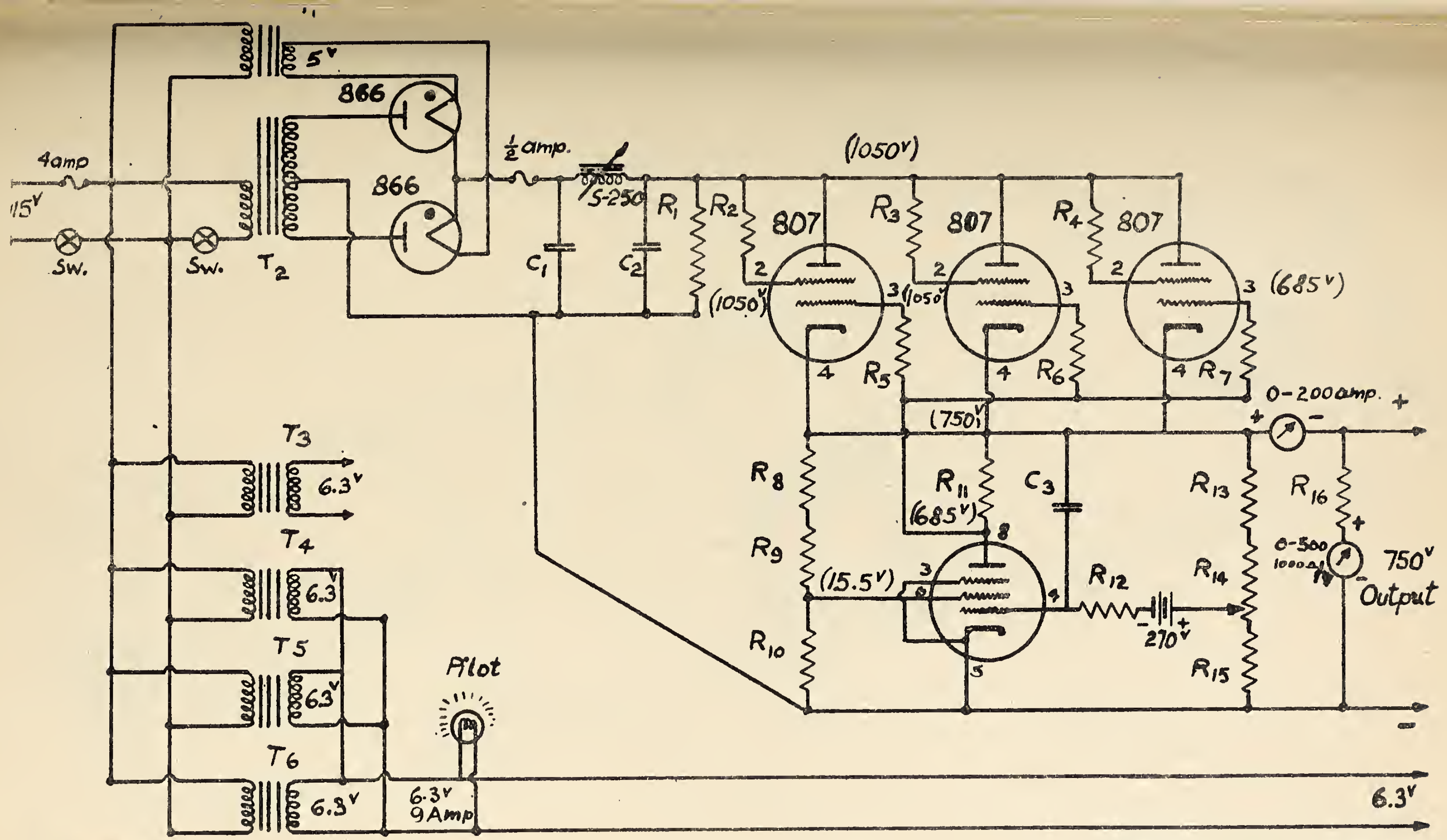
Legend:
C_1 = 1 μfd
C_2 = 8 μfd
C_3 = 8 μfd
C_4 = 4 μfd
C_5 = 4 μfd

R_1 = 50K-10W
R_2 = 100 Ω
R_3 = 1 Meg Ω
R_4 = 1 Meg Ω
R_5 = 1 Meg Ω
R_6 = 75K

R_7 = 500K
R_8 = 100K
R_9 = 3 K
T_1 = T13R13
T_2 = T13R08

NATIONAL BUREAU OF STANDARDS
WASHINGTON, D. C.
RADIO SECTION
SUBJECT
Regulated Power Supply
DESIGNER RCE
DELINEATOR AAF
DATE
May 1946

FIG. 5A


4amp
115V
Sw.
Sw.
T2
5V
866
866
½ amp.
S-250
C1
C2
R1
R2
R3
R4
807
807
807
(1050V)
(1050V)
(1050V)
(685V)
2
3
4
R5
R6
R7
(750V)
0-200 amp.
+
−
R8
R9
R10
R11
(685V)
8
3
4
5
(15.5V)
C3
R12
270V
R13
R14
R15
R16
0-500 1000Ω
750V
Output
T3
6.3V
T4
6.3V
T5
6.3V
T6
6.3V
Pilot
6.3V 9Amp
6.3V

Legend:

R_1 = 100K-20W,
R_2 = BW-100Ω,
R_3 = BW-100Ω,
R_4 = BW-100Ω,
R_5 = BW-100Ω,
R_6 = BW-100Ω,
R_7 = BW-100Ω,

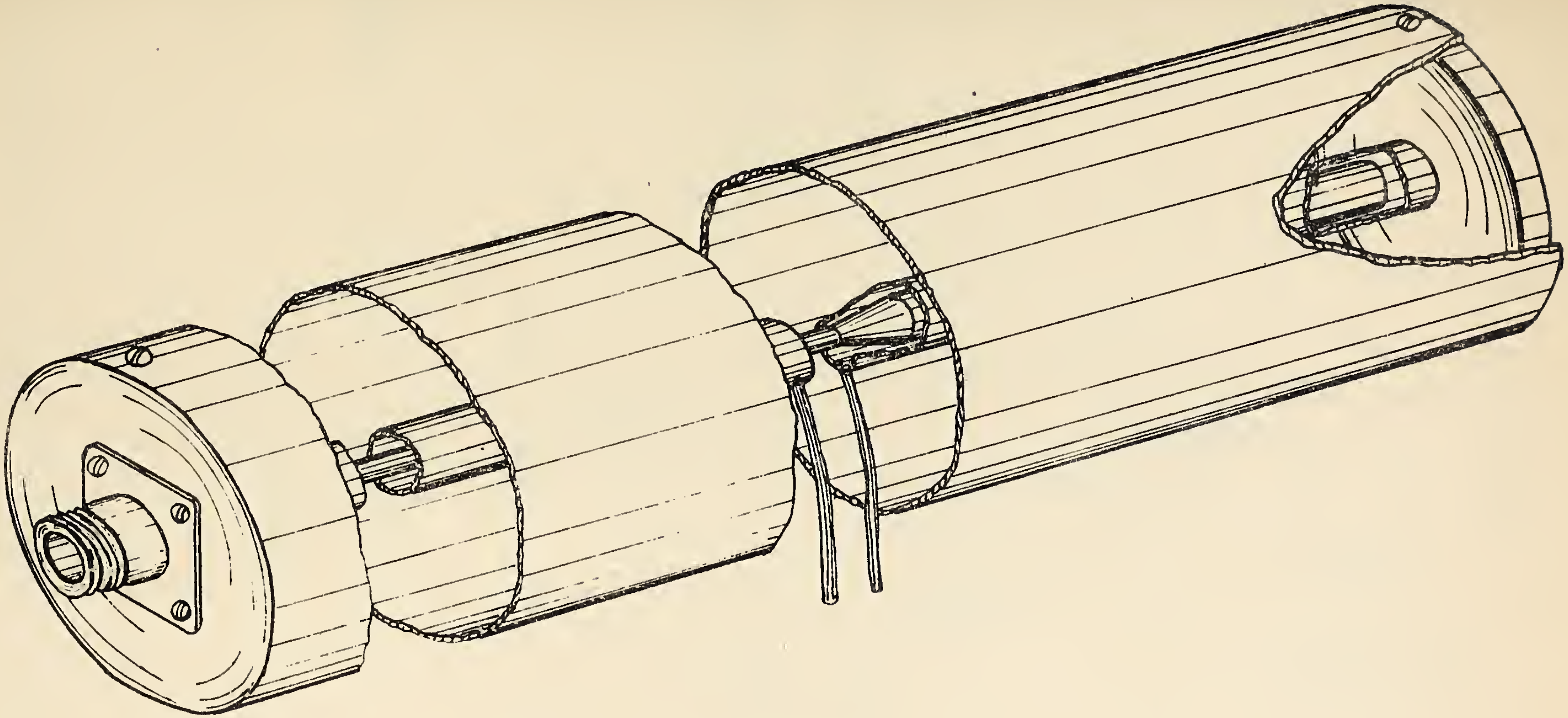
R_8 = 200K-20W,
R_9 = 15K-10W,
R_{10} = 4K-10W
R_{11} = 1 Meg-5W,
R_{12} = BW-500Ω,
R_{13} = 200K-20W,
R_{14} = BW-20K,

R_{15} = 100K-10W,
R_{16} = 5 Meg
C_1 = 1μfd. 1000WV,
C_2 = 4μfd, 1000WV,
C_3 = 4μfd 1000WV,

T_1 = B5-859. Fil. Xformer
T_2 = T-19 P58. Plate Xformer
T_3 =, T_4 =, T_5 =, T_6 = } B5-860
S-250 = Swinging Choke, 250 ma.

NATIONAL BUREAU OF STANDARDS
WASHINGTON, D. C.
RADIO SECTION
SUBJECT
750V-Power Supply
DESIGNER Reggia 9/15/46
DELINEATOR AAF

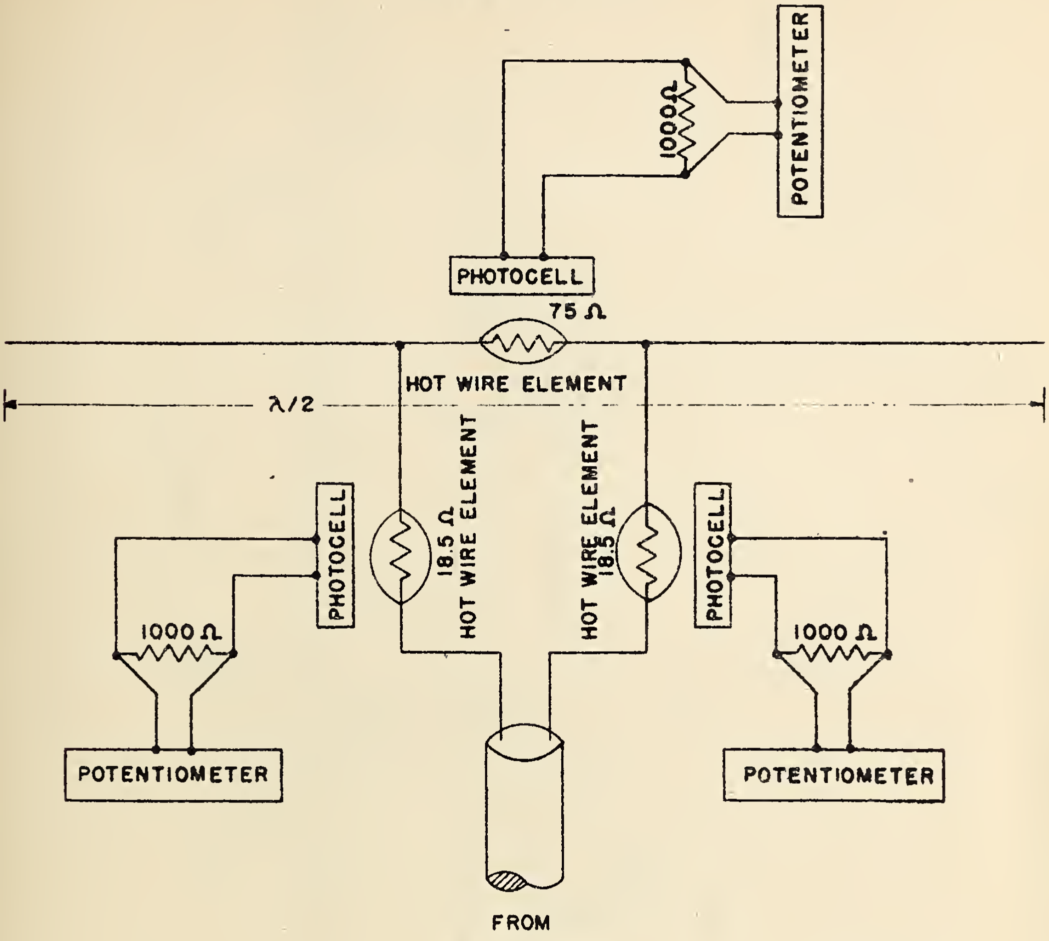
FIG. 5B



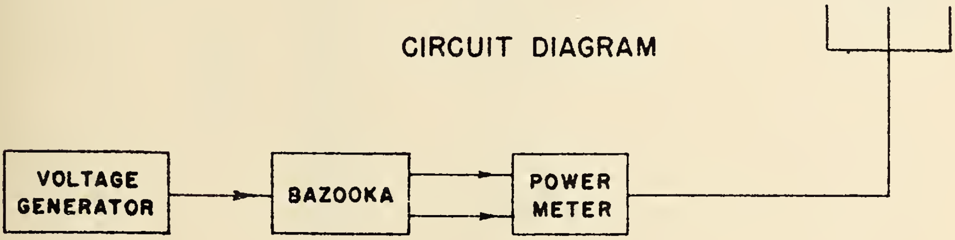
PERSPECTIVE DRAWING OF
WIDE BAND TRANSMISSION LINE TRANSFORMER

Fig. 6.

POWER METER

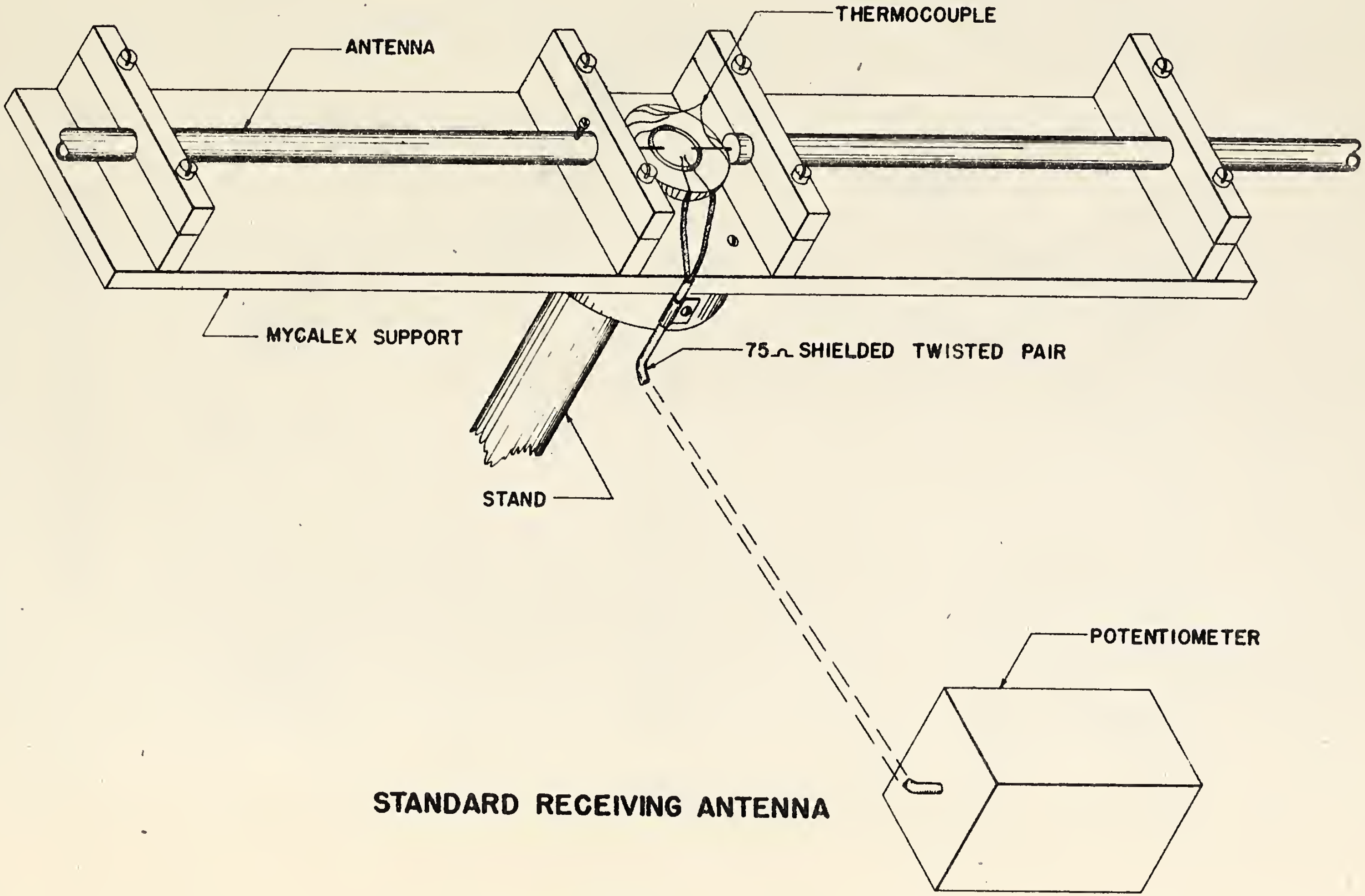

POTENTIOMETER
1000Ω
PHOTOCELL
75 Ω
HOT WIRE ELEMENT
λ/2
18.5 Ω
HOT WIRE ELEMENT
HOT WIRE ELEMENT
18.5 Ω
PHOTOCELL
PHOTOCELL
1000 Ω
1000 Ω
POTENTIOMETER
POTENTIOMETER
FROM BAZOOKA

CIRCUIT DIAGRAM


ANTENNA
VOLTAGE GENERATOR
BAZOOKA
POWER METER

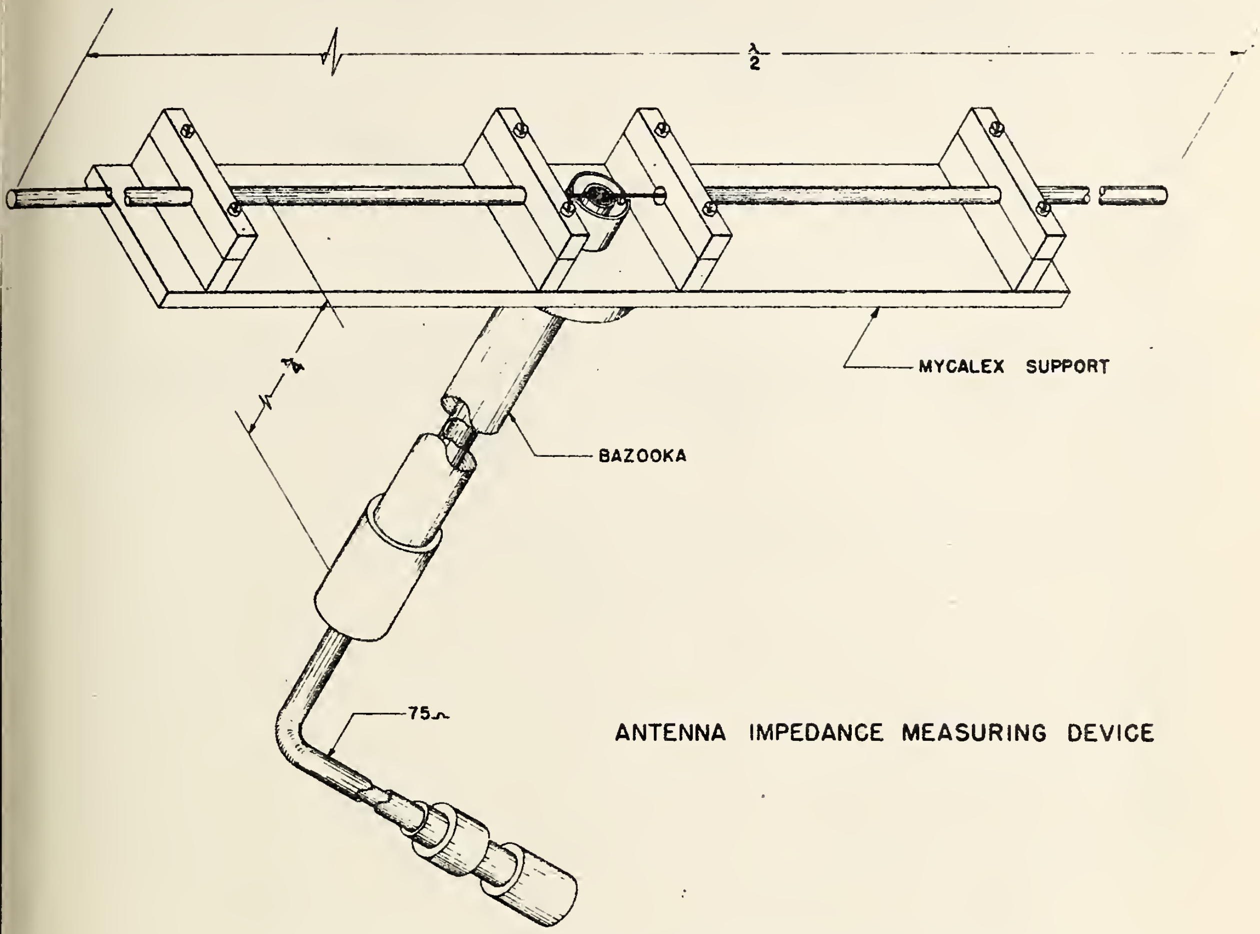
BLOCK DIAGRAM

FIG. 7

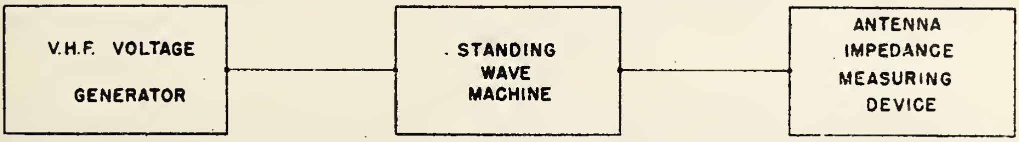

THERMOCOUPLE
ANTENNA
MYCALEX SUPPORT
75Ω SHIELDED TWISTED PAIR
STAND
POTENTIOMETER

STANDARD RECEIVING ANTENNA

Fig. 8


λ/2
MYCALEX SUPPORT
λ/4
BAZOOKA
75Ω

ANTENNA IMPEDANCE MEASURING DEVICE


V.H.F. VOLTAGE GENERATOR
STANDING WAVE MACHINE
ANTENNA IMPEDANCE MEASURING DEVICE

BLOCK DIAGRAM OF DEVICE IN OPERATION

Fig. 9

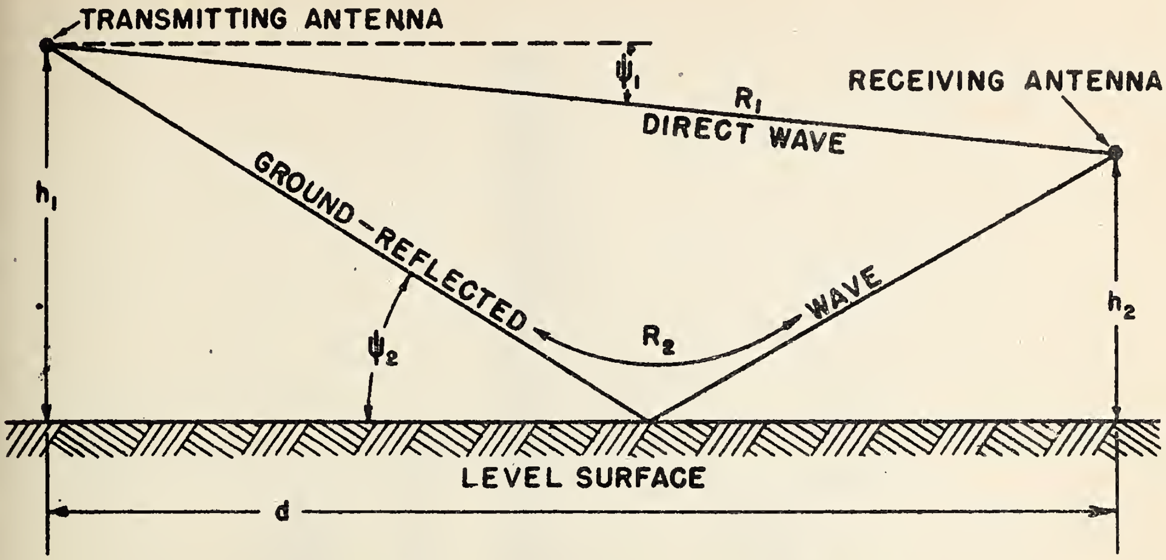

TRANSMITTING ANTENNA
ψ_1
R_1
DIRECT WAVE
RECEIVING ANTENNA
h_1
GROUND-REFLECTED WAVE
R_2
ψ_2
h_2
LEVEL SURFACE
d

ILLUSTRATION OF IDEAL WAVE PATHS

Fig. 10

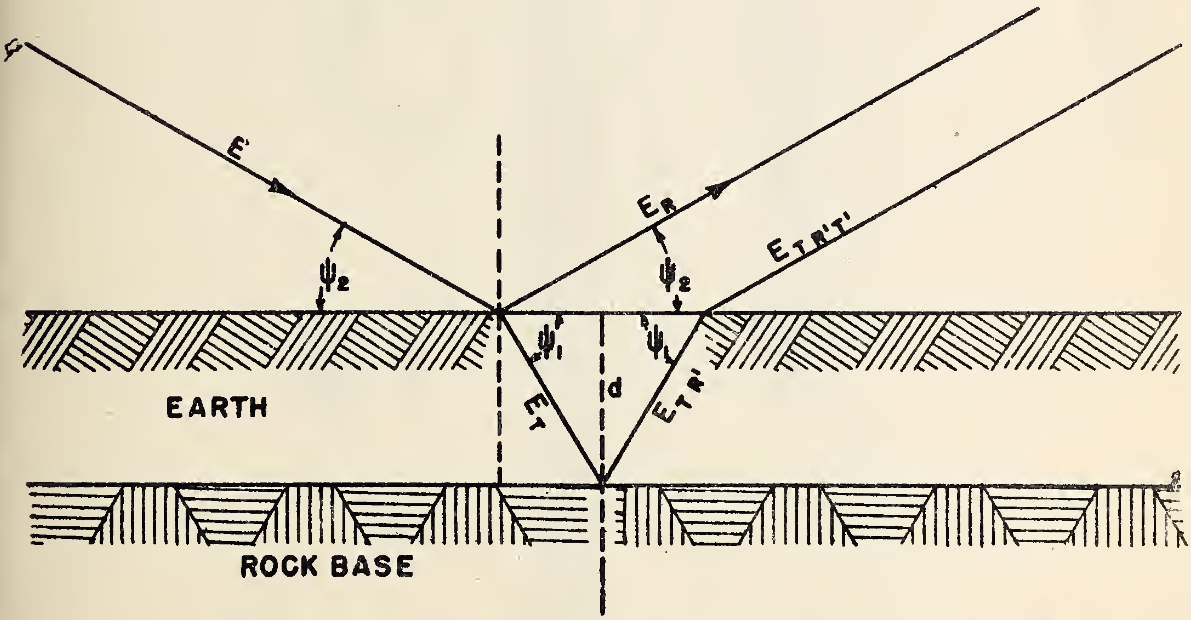

E
E_R
$E_{TR'T'}$
ψ_2
ψ_2
ψ_1
ψ_1
d
E_T
$E_{TR'}$
EARTH
ROCK BASE

ILLUSTRATION OF GROUND-REFLECTED WAVE PATHS WITH SUBTERANEAN DISCONTINUITIES

Fig. 11

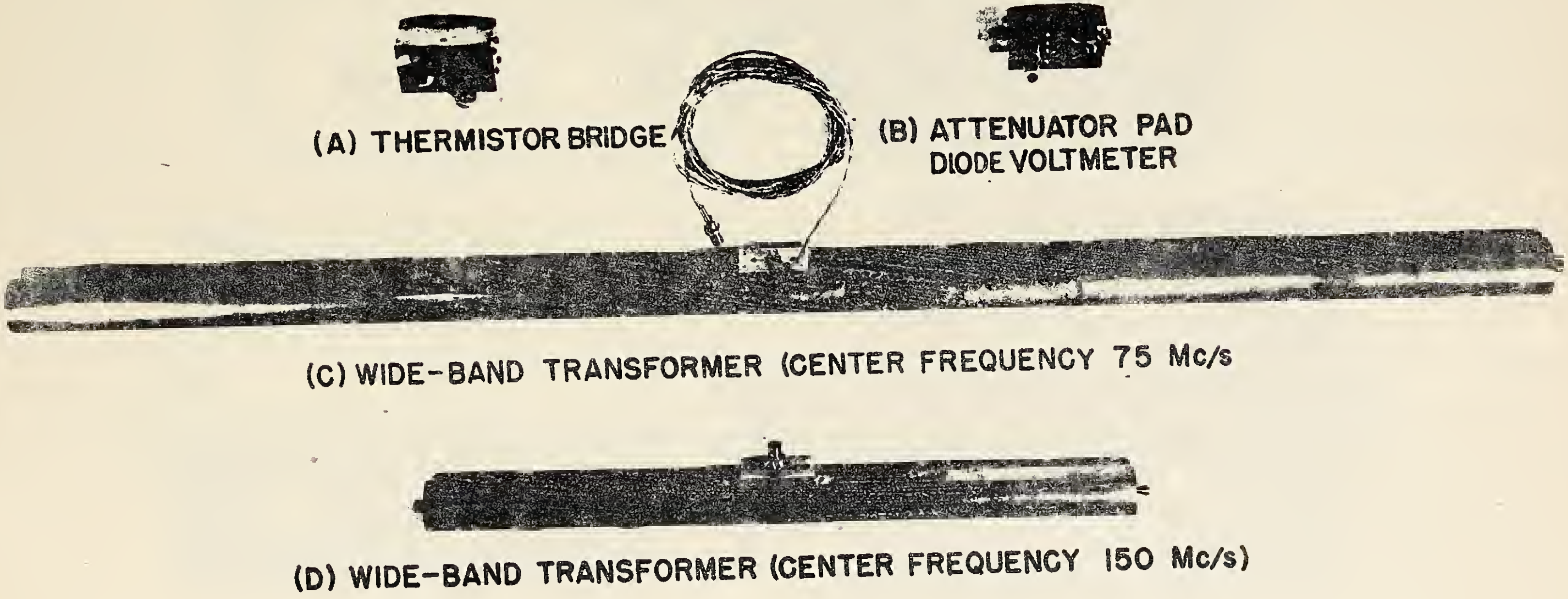
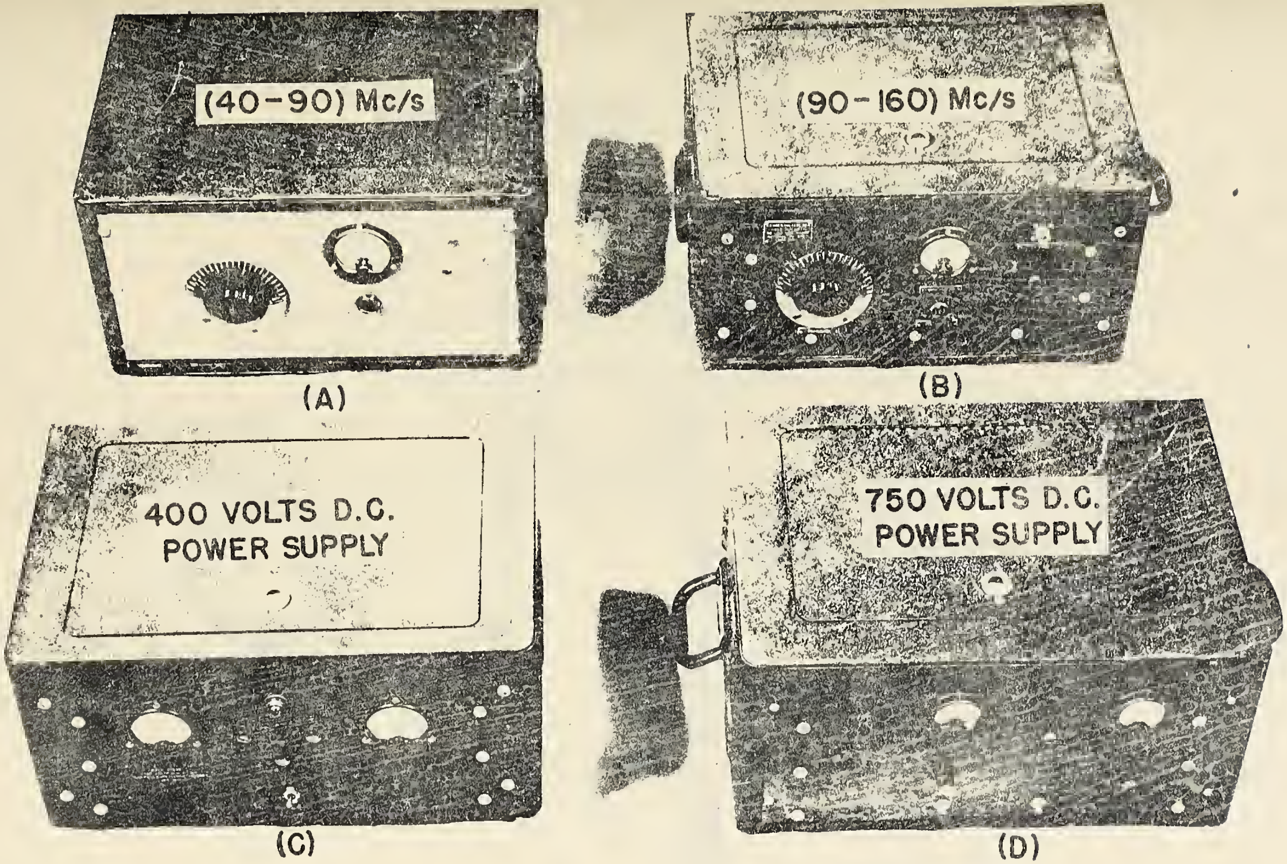

(A) THERMISTOR BRIDGE
(B) ATTENUATOR PAD
DIODE VOLTMETER
(C) WIDE-BAND TRANSFORMER (CENTER FREQUENCY 75 Mc/s
(D) WIDE-BAND TRANSFORMER (CENTER FREQUENCY 150 Mc/s)

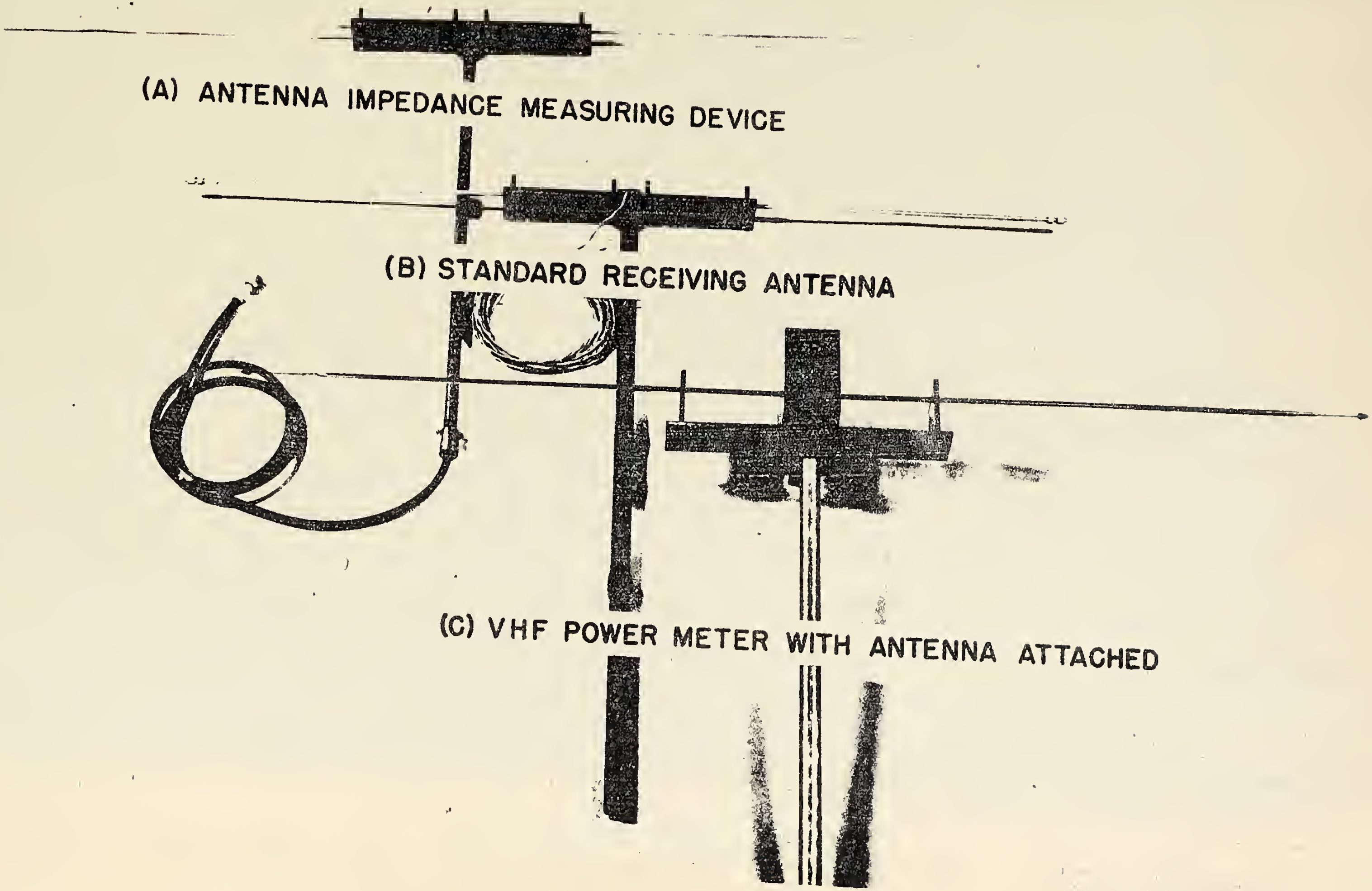
PHOTO NO. 1


(40-90) Mc/s
(90-160) Mc/s
400 VOLTS D.C. POWER SUPPLY
750 VOLTS D.C. POWER SUPPLY

(A) (B) (C) (D)

V H F VOLTAGE GENERATORS AND ASSOCIATED POWER SUPPLIES

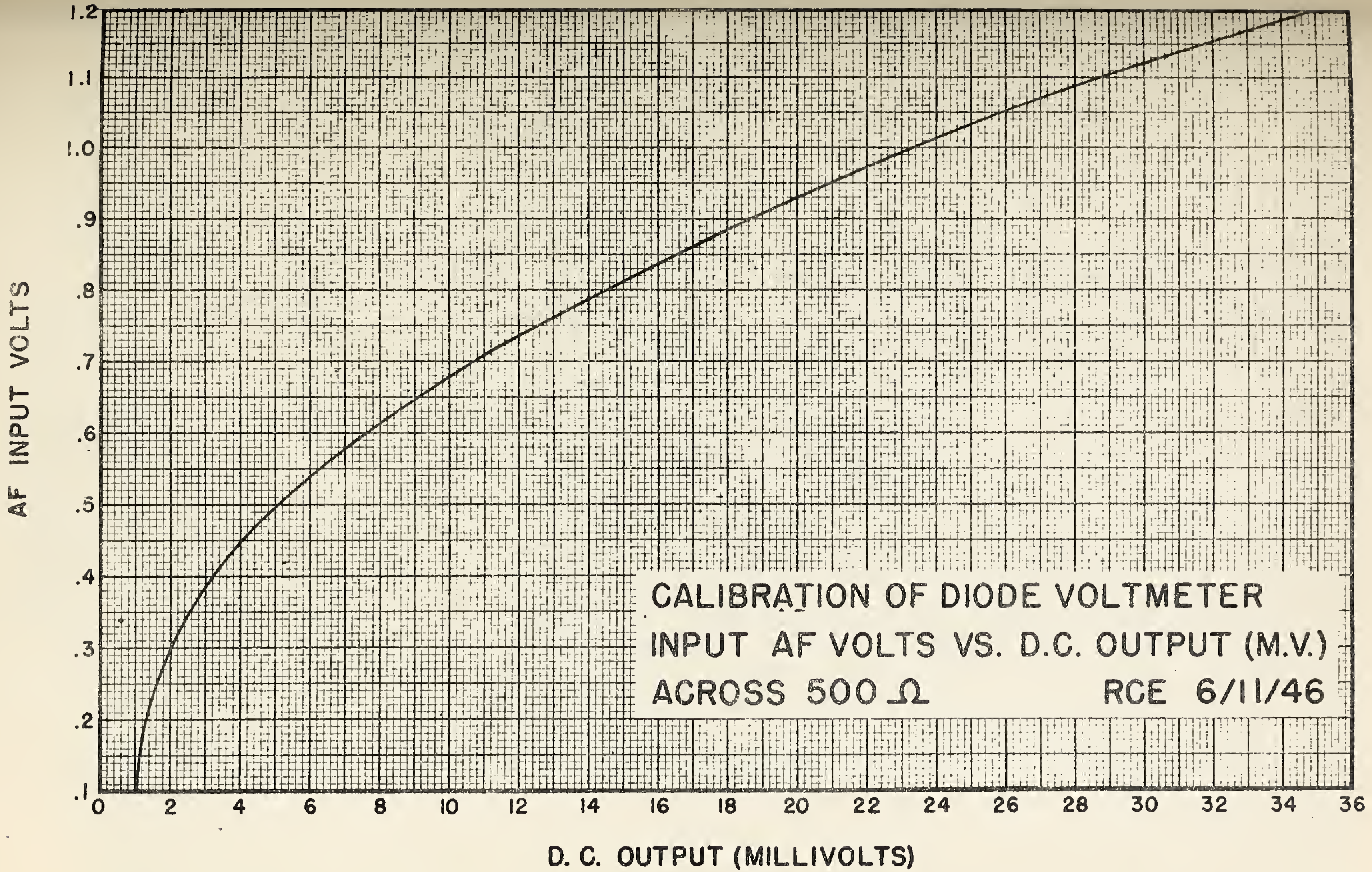
PHOTO NO. 2


(A) ANTENNA IMPEDANCE MEASURING DEVICE

(B) STANDARD RECEIVING ANTENNA

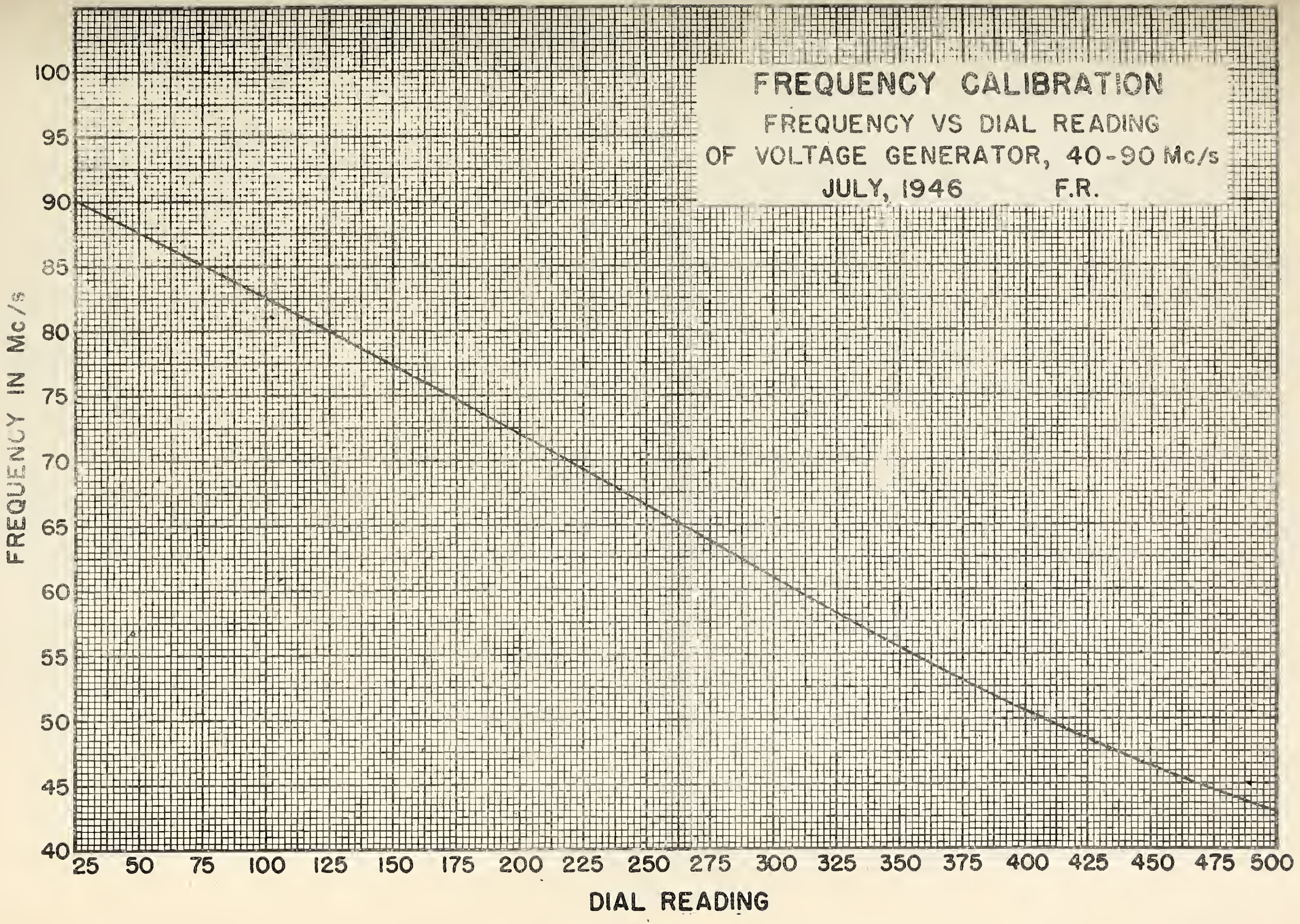
(C) VHF POWER METER WITH ANTENNA ATTACHED

PHOTO NO. 3

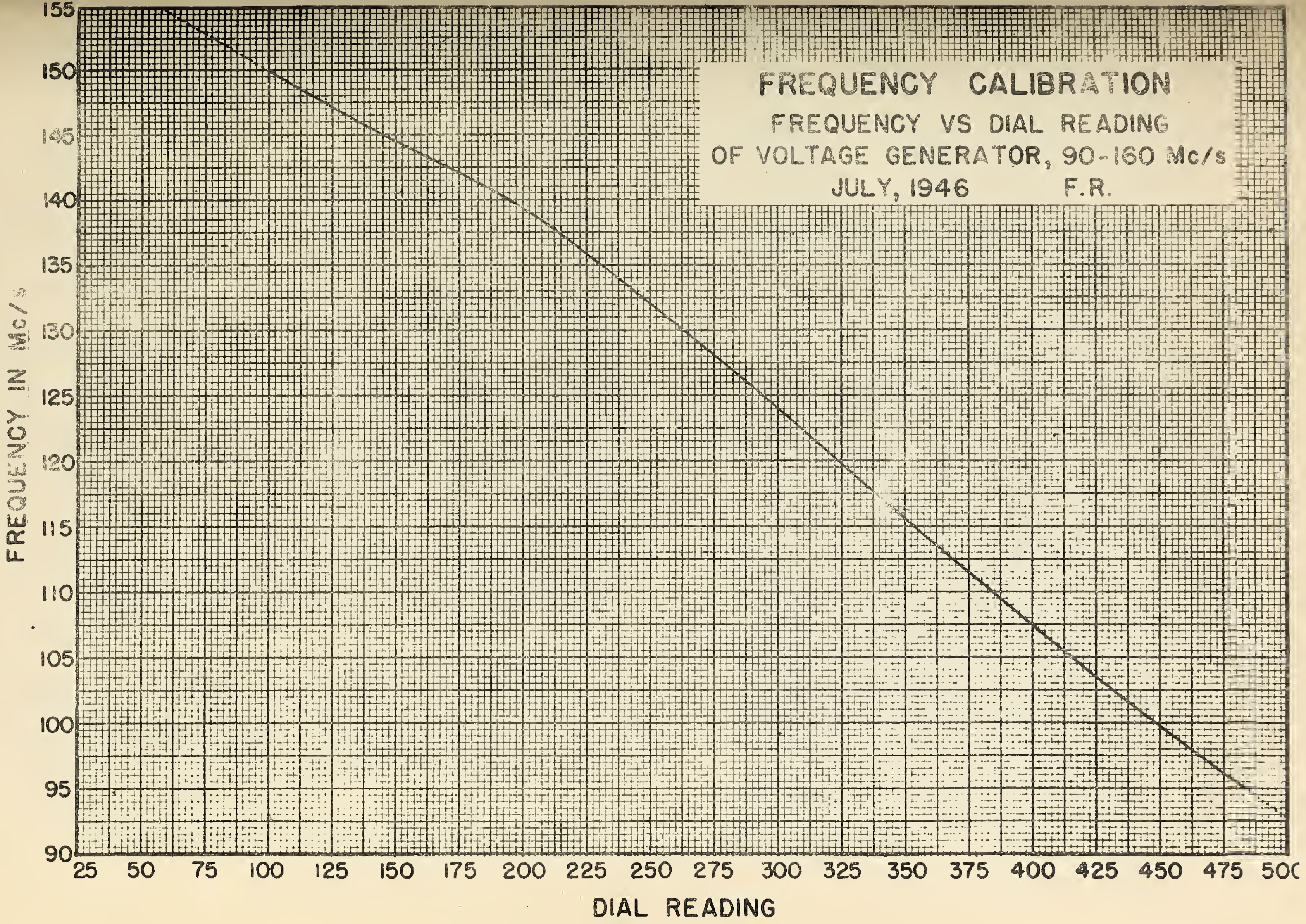


CALIBRATION OF DIODE VOLTMETER
INPUT AF VOLTS VS. D.C. OUTPUT (M.V.)
ACROSS 500 Ω RCE 6/11/46

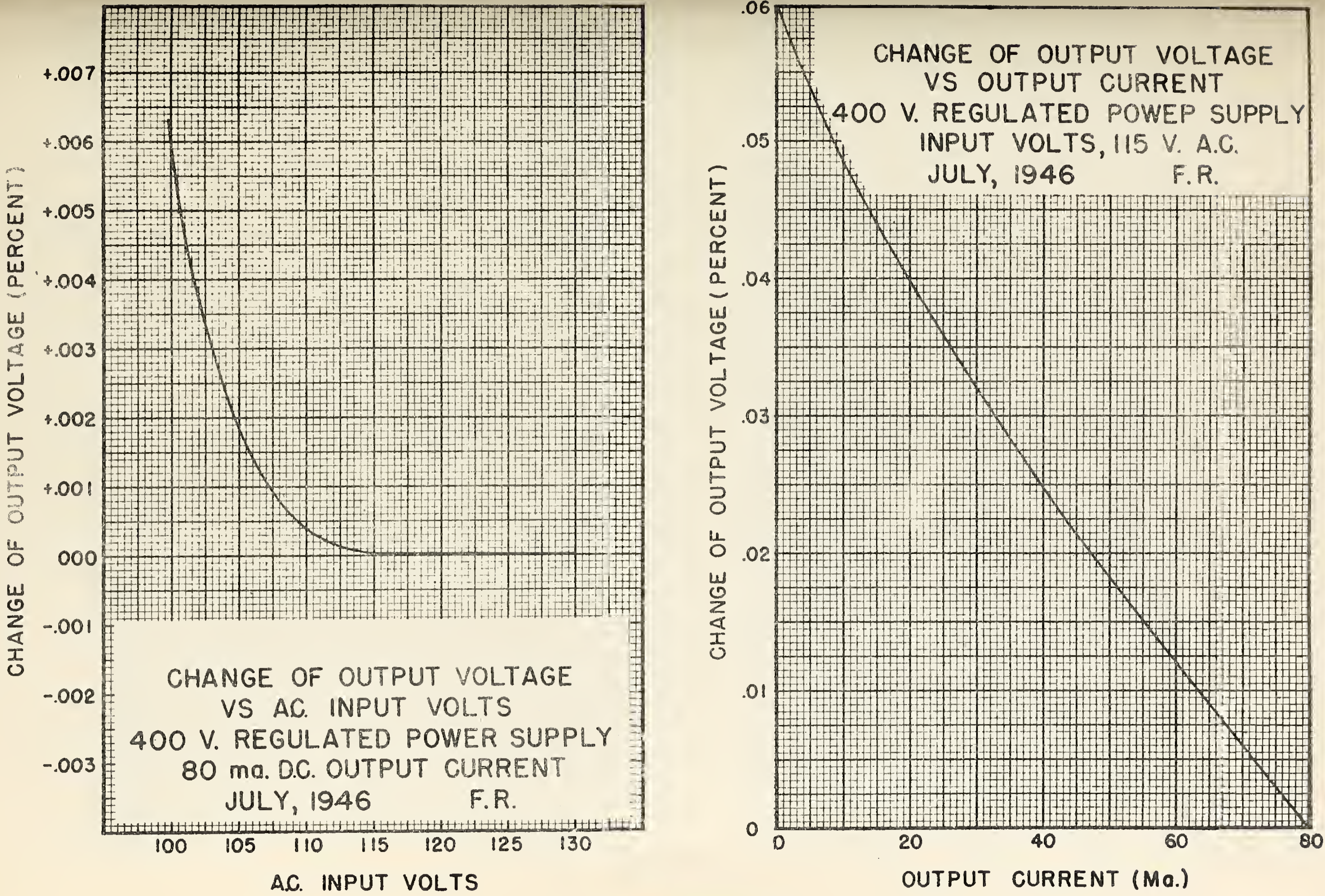
GRAPH NO. I


FREQUENCY CALIBRATION
FREQUENCY VS DIAL READING
OF VOLTAGE GENERATOR, 40-90 Mc/s
JULY, 1946 F.R.
FREQUENCY IN Mc/s
100
95
90
85
80
75
70
65
60
55
50
45
40
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
DIAL READING

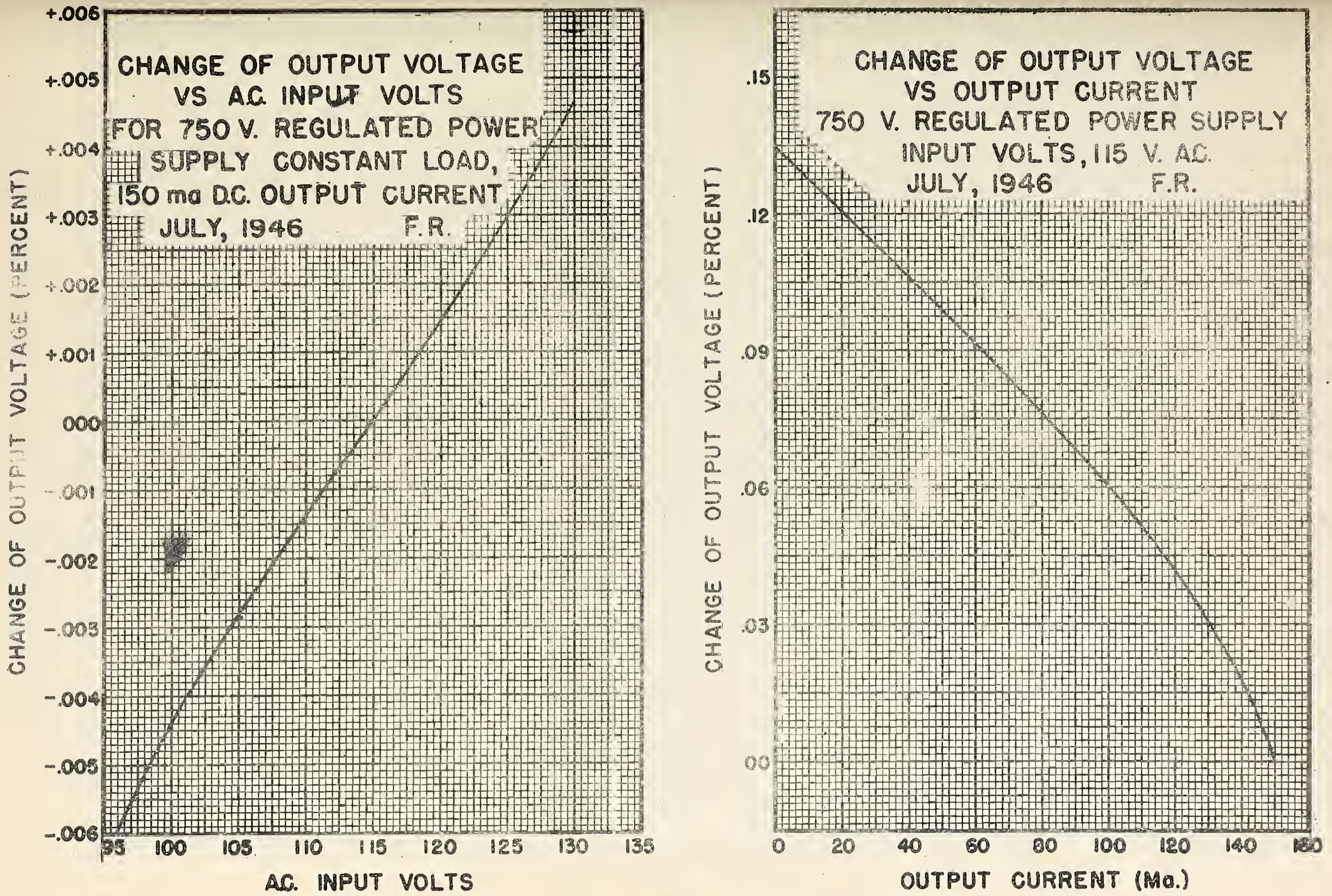
GRAPH NO. 2


FREQUENCY CALIBRATION
FREQUENCY VS DIAL READING
OF VOLTAGE GENERATOR, 90-160 Mc/s
JULY, 1946 F.R.
FREQUENCY IN Mc/s
155
150
145
140
135
130
125
120
115
110
105
100
95
90
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
DIAL READING

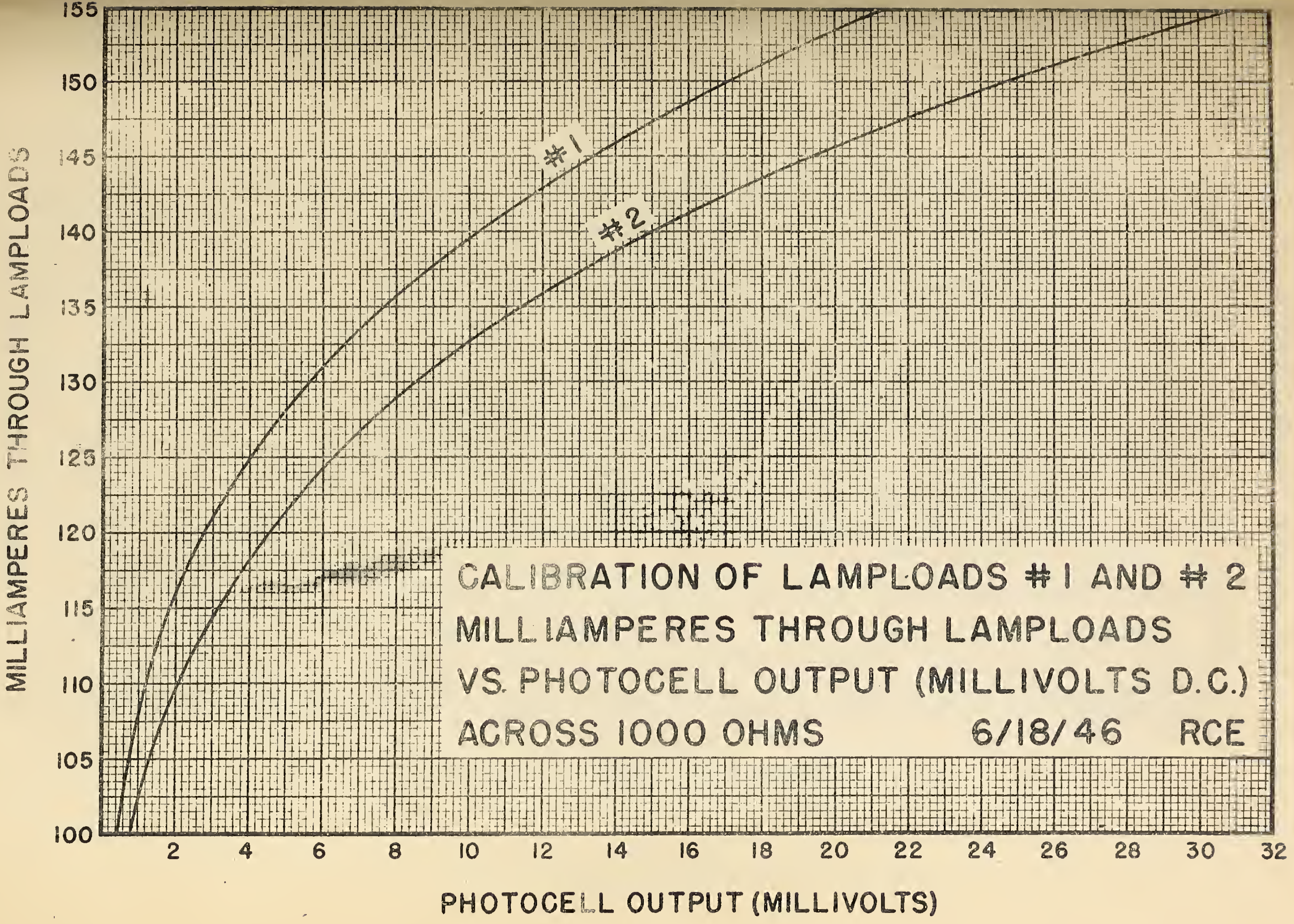
GRAPH NO. 3


+.007
+.006
+.005
+.004
+.003
+.002
+.001
000
-.001
-.002
-.003
CHANGE OF OUTPUT VOLTAGE (PERCENT)
100
105
110
115
120
125
130
A.C. INPUT VOLTS
CHANGE OF OUTPUT VOLTAGE
VS A.C. INPUT VOLTS
400 V. REGULATED POWER SUPPLY
80 ma. D.C. OUTPUT CURRENT
JULY, 1946 F.R.
.06
.05
.04
.03
.02
.01
0
CHANGE OF OUTPUT VOLTAGE (PERCENT)
0
20
40
60
80
OUTPUT CURRENT (Ma.)
CHANGE OF OUTPUT VOLTAGE
VS OUTPUT CURRENT
400 V. REGULATED POWEP SUPPLY
INPUT VOLTS, 115 V. A.C.
JULY, 1946 F.R.

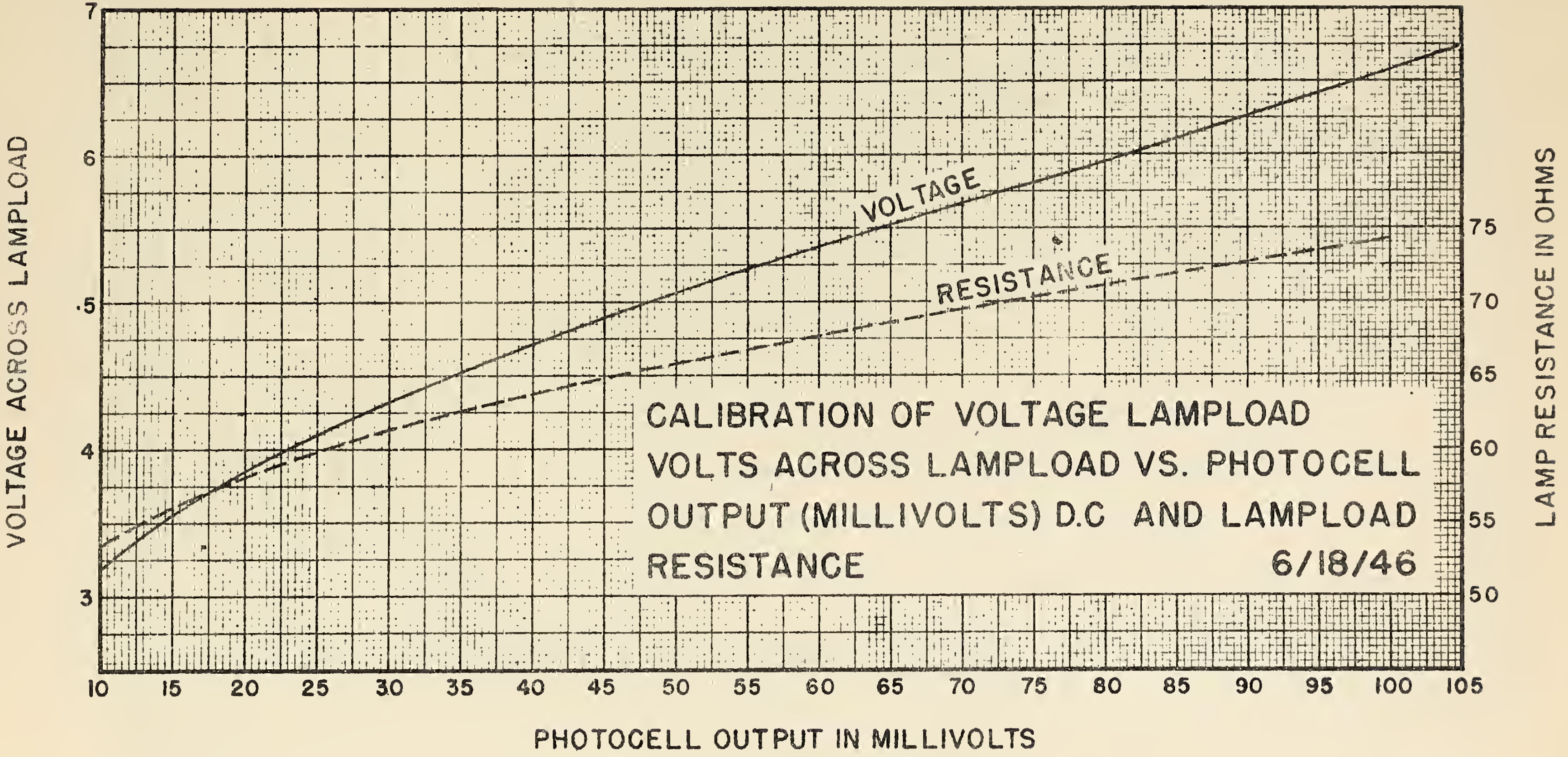
GRAPH NO. 4.


CHANGE OF OUTPUT VOLTAGE
VS A.C. INPUT VOLTS
FOR 750 V. REGULATED POWER
SUPPLY CONSTANT LOAD,
150 ma D.C. OUTPUT CURRENT
JULY, 1946 F.R.
CHANGE OF OUTPUT VOLTAGE (PERCENT)
+.006
+.005
+.004
+.003
+.002
+.001
.000
-.001
-.002
-.003
-.004
-.005
-.006
95
100
105
110
115
120
125
130
135
A.C. INPUT VOLTS
CHANGE OF OUTPUT VOLTAGE
VS OUTPUT CURRENT
750 V. REGULATED POWER SUPPLY
INPUT VOLTS, 115 V. A.C.
JULY, 1946 F.R.
CHANGE OF OUTPUT VOLTAGE (PERCENT)
.15
.12
.09
.06
.03
.00
0
20
40
60
80
100
120
140
160
OUTPUT CURRENT (Ma.)

GRAPH NO. 5

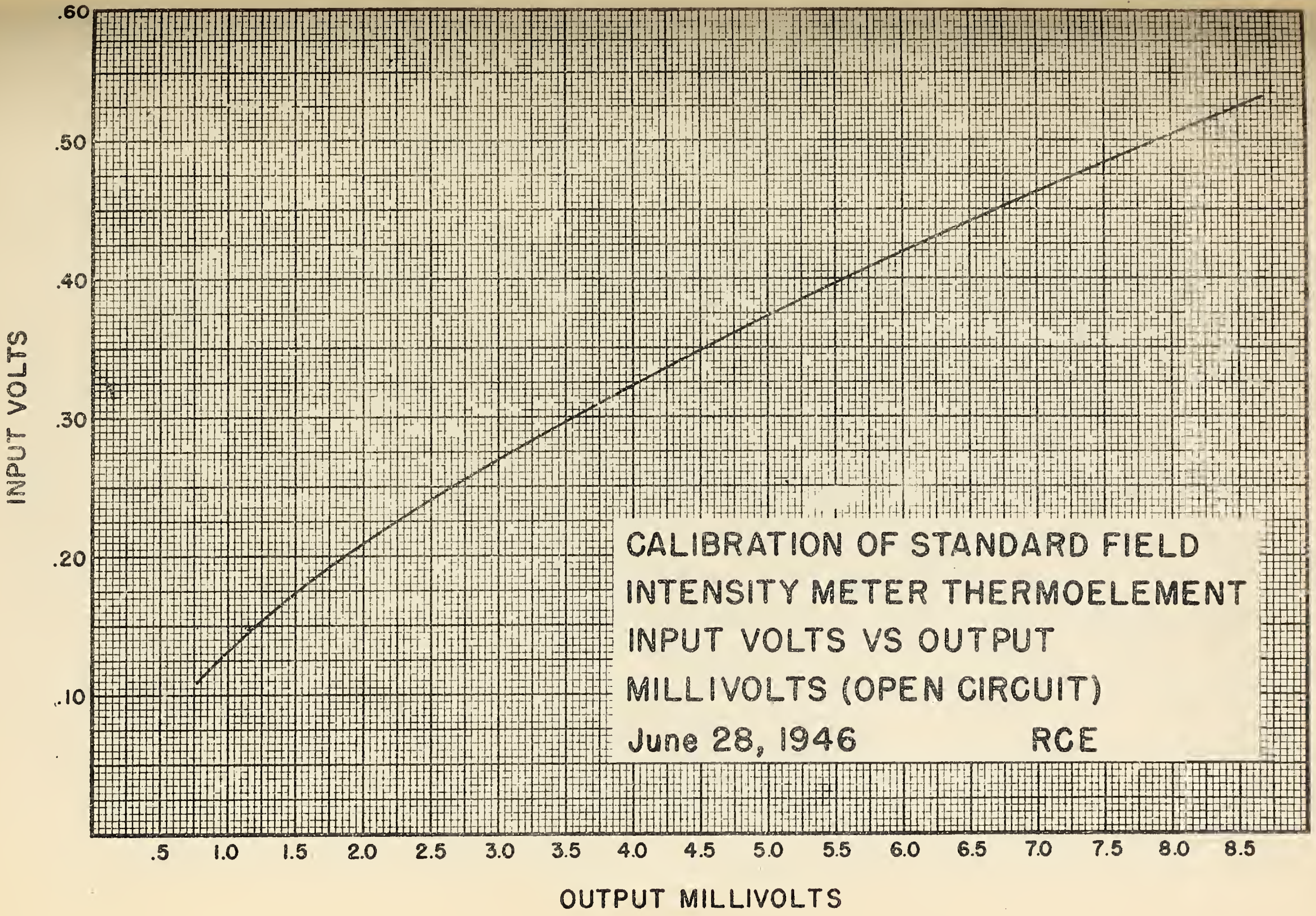

CALIBRATION OF LAMPLOADS #1 AND # 2
MILLIAMPERES THROUGH LAMPLOADS
VS. PHOTOCELL OUTPUT (MILLIVOLTS D.C.)
ACROSS 1000 OHMS 6/18/46 RCE
#1
#2
MILLIAMPERES THROUGH LAMPLOADS
100
105
110
115
120
125
130
135
140
145
150
155
PHOTOCELL OUTPUT (MILLIVOLTS)
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

GRAPH NO. 6

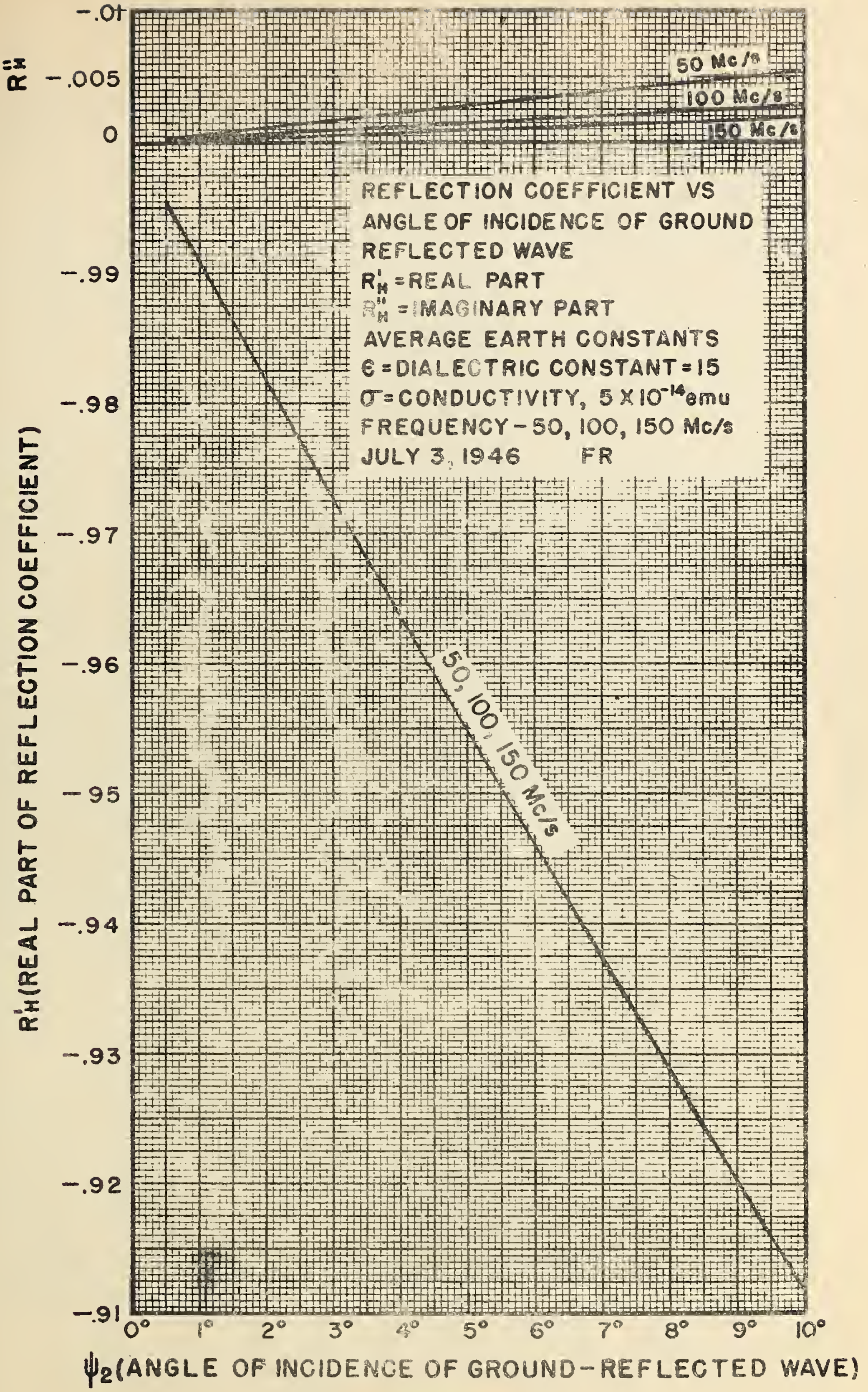


CALIBRATION OF VOLTAGE LAMPLOAD
VOLTS ACROSS LAMPLOAD VS. PHOTOCELL
OUTPUT (MILLIVOLTS) D.C AND LAMPLOAD
RESISTANCE 6/18/46

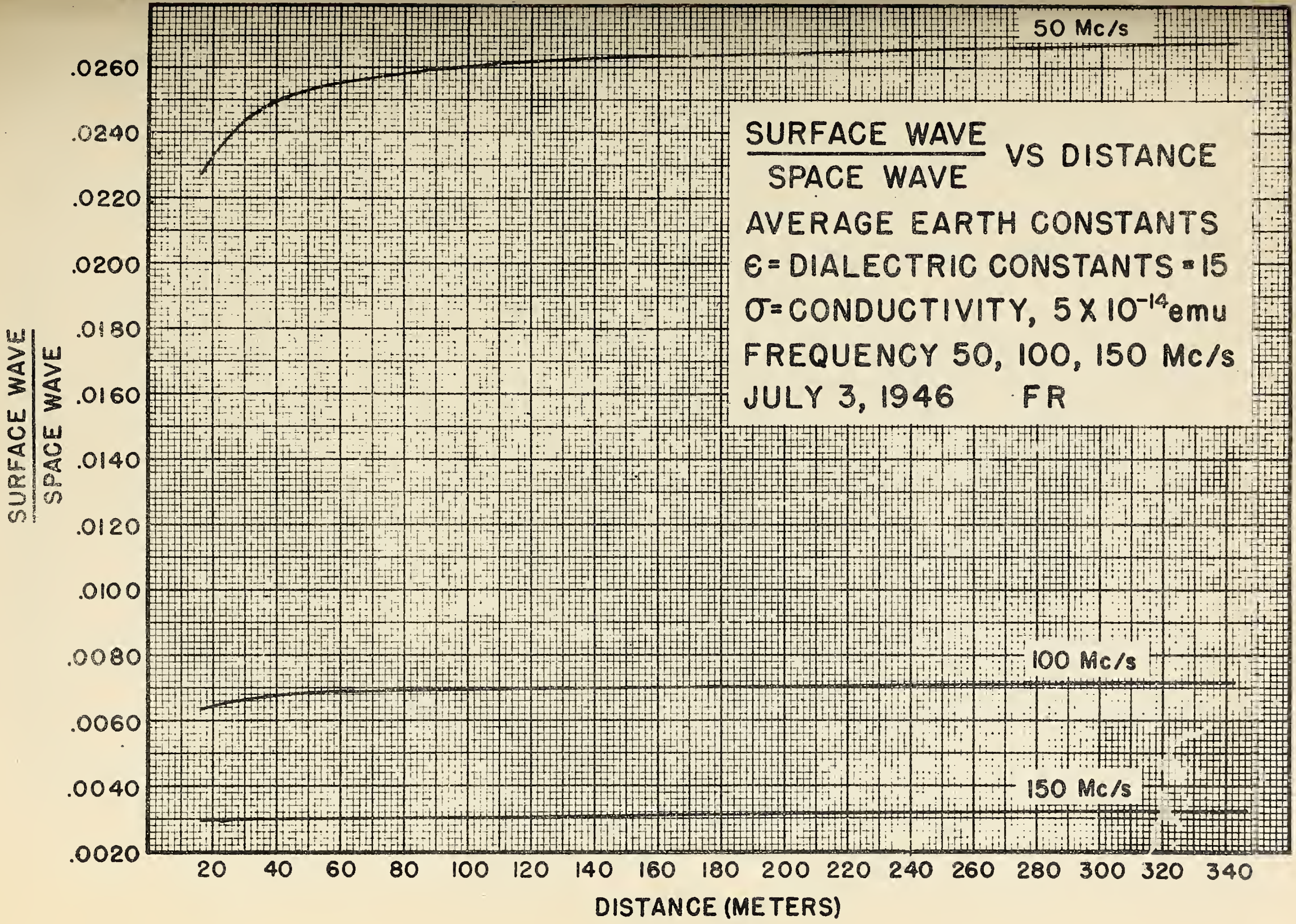
GRAPH NO.7


CALIBRATION OF STANDARD FIELD
INTENSITY METER THERMOELEMENT
INPUT VOLTS VS OUTPUT
MILLIVOLTS (OPEN CIRCUIT)
June 28, 1946 RCE
INPUT VOLTS
.60
.50
.40
.30
.20
.10
OUTPUT MILLIVOLTS
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5

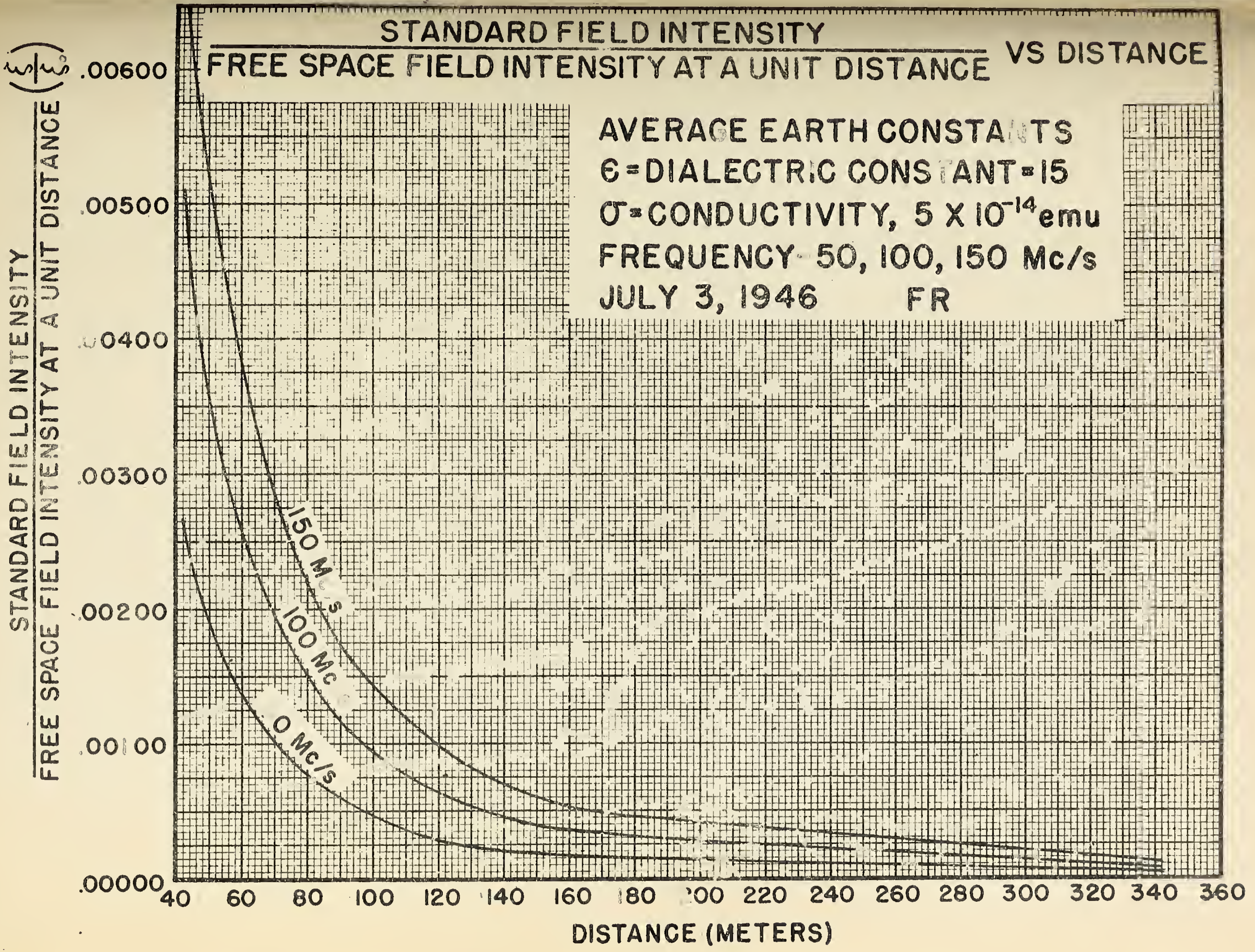
GRAPH NO. 8


REFLECTION COEFFICIENT VS
ANGLE OF INCIDENCE OF GROUND REFLECTED WAVE
R'_H = REAL PART
R''_H = IMAGINARY PART
AVERAGE EARTH CONSTANTS
ϵ = DIALECTRIC CONSTANT = 15
σ = CONDUCTIVITY, 5×10^{-14} emu
FREQUENCY – 50, 100, 150 Mc/s
JULY 3, 1946 FR
50 Mc/s
100 Mc/s
150 Mc/s
50, 100, 150 Mc/s
R''_H
–.01
–.005
0
–.99
–.98
–.97
–.96
–.95
–.94
–.93
–.92
–.91
R'_H (REAL PART OF REFLECTION COEFFICIENT)
0°
1°
2°
3°
4°
5°
6°
7°
8°
9°
10°
ψ_2 (ANGLE OF INCIDENCE OF GROUND–REFLECTED WAVE)

GRAPH NO. 9


50 Mc/s
SURFACE WAVE / SPACE WAVE VS DISTANCE
AVERAGE EARTH CONSTANTS
ϵ = DIALECTRIC CONSTANTS = 15
σ = CONDUCTIVITY, 5 X 10^-14 emu
FREQUENCY 50, 100, 150 Mc/s
JULY 3, 1946 FR
100 Mc/s
150 Mc/s
.0260
.0240
.0220
.0200
.0180
.0160
.0140
.0120
.0100
.0080
.0060
.0040
.0020
SURFACE WAVE / SPACE WAVE
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (METERS)

GRAPH NO.10

STANDARD FIELD INTENSITY / FREE SPACE FIELD INTENSITY AT A UNIT DISTANCE VS DISTANCE
AVERAGE EARTH CONSTANTS
ϵ = DIALECTRIC CONSTANT = 15
σ = CONDUCTIVITY, 5 X 10⁻¹⁴ emu
FREQUENCY 50, 100, 150 Mc/s
JULY 3, 1946 FR
STANDARD FIELD INTENSITY / FREE SPACE FIELD INTENSITY AT A UNIT DISTANCE
(ω/ω)
.00600
.00500
.00400
.00300
.00200
.00100
.00000
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
DISTANCE (METERS)
150 Mc/s
100 Mc
0 Mc/s

GRAPH NO. 11